NEARSHORE SEDIMENT TRANSPORT STUDY WORKSHOP ON INSTRUMENTATION FOR NEARSHORE PROCESSES

JUNE 16-17, 1977

LA JOLLA, CALIFORNIA

UNIVERSITY OF CALIFORNIA

SEA GRANT COLLEGE PROGRAM

IMR REFERENCE 78–102

INSTITUTE OF MARINE RESOURCES
UNIVERSITY OF CALIFORNIA
LA JOLLA, CALIFORNIA 92093

NEARSHORE SEDIMENT TRANSPORT STUDY

A Sea Grant National Program

WORKSHOP ON INSTRUMENTATION FOR NEARSHORE PROCESSES

June 16-17, 1977

La Jolla, California

IMR Reference 78-102

Sea Grant Publication No. 62

Institute of Marine Resources
Mail Code A-032
University of California
La Jolla, California 92093

APPROVED FOR DISTRIBUTION

John D. Isaacs, Director
Institute of Marine Resources

The University of California Sea Grant College Program attempts to foster discussion of important marine issues by publishing reports, sometimes dealing with controversial material. A balanced presentation is always attempted. When specific views are presented, they are those of the authors, not of the Sea Grant College Program, which does not take stands on issues.

ORDERING PUBLICATIONS

Copies of this and other University of California Sea Grant publications are available from:

Marine Advisory Programs
Extension Wildlife and Sea Grant
554 Hutchison Hall
University of California
Davis, California 95616

Please include author, title and publication number.

NEARSHORE SEDIMENT TRANSPORT STUDY WORKSHOP ON INSTRUMENTATION FOR NEARSHORE PROCESSES

June 16-17, 1977

La Jolla, California

Convened by the NSTS Steering Committee:

Mr. Arthur G. Alexiou	Office of Sea Grant
Dr. Robert S. Dean	University of Delaware
Dr. David B. Duane	Office of Sea Grant
Dr. Douglas L. Inman	University of California, San Diego
Dr. Bernard Le Mehaute	Tetra Tech, Inc.
Mr. Thorndike Saville	Coastal Engineering Research Center
Dr. Richard J. Seymour	California Department of Navigation and Ocean Development
Dr. Edward B. Thornton	Navy Postgraduate School

Hosted by:

Institute of Marine Resources,
Scripps Institution of Oceanography

and

University of California Sea Grant
College Program

Published and distributed by the
California Sea Grant College Program

IMR REFERENCE 78-102 SEA GRANT PUBLICATION 62

PREFACE:

The Nearshore Sediment Transport Study is a National Program, sponsored by the Office of Sea Grant, Washington, D. C., with the objective of developing improved engineering relationships for sediment transport by waves and currents in the nearshore region.

The NSTS Steering Committee, recognizing the importance and complexity of the measurement requirements for this program, directed that a workshop be sponsored to:

1) Determine the present capabilities for measuring and recording nearshore parameters related to sediment transport.

2) Determine the specific needs of NSTS for instrumentation.

3) Discover areas requiring further development to meet NSTS needs.

These proceedings provide a record of the papers presented and the findings of the working group sessions at the resulting workshop.

NOTE: As these proceedings went to press, the program title was changed to its present form to be more descriptive. Many of the paper manuscripts utilized the previous form in which "National" was used in place of "Nearshore."

Inquiries concerning the Nearshore Sediment Transport Study should be directed to:

Dr. R. J. Seymour, Project Leader NSTS
Mail Code A-022
UCSD
La Jolla, CA 92093

NEARSHORE SEDIMENT TRANSPORT STUDY
WORKSHOP ON INSTRUMENTATION
FOR NEARSHORE PROCESSES

CONTENTS

THURSDAY, JUNE 16, 1977

FRIDAY, JUNE 17, 1977

REVIEW OF NATIONAL SEDIMENT TRANSPORT STUDY

R. J. Seymour
Scripps Institution
of Oceanography

The overall objective of the National Sediment Transport Study (NSTS) is to perfect relations for the prediction of sediment transport by waves and currents in the nearshore environment. Initially, this program will deal with the problems of sediment transport along straight coastlines. Detailed studies of the mechanics of water-sediment interaction will be coordinated into a working model, and tested by two or more "large scale" field experiments along the coast of the United States.

Results of the study will provide coastal engineers with a model that will allow useful prediction of the magnitude and direction of sediment transport under waves and currents on relatively straight sections of coastlines. This model will utilize measurement schemes that provide the necessary data in a practical and economical fashion. Concurrently with the later stages of this study, NOAA is proposing the inauguration of a National Wave Climate Survey. One of the purposes of this Survey will be to provide nearshore data for sediment management. The NSTS will provide meaningful direction to the Wave Climate Survey in terms of the type and frequency of measurement and the location of measuring stations. At the same time, the Wave Climate Survey will be beginning to develop the data base necessary to apply the findings of this study. To develop a model which will have sufficiently universal applicability, it is necessary to understand the physics of sediment motions under a range of conditions. Therefore, intermediate objectives of this program are to characterize those physical processes and parameters that have significant effects on sediment motion. Only those investigations that continue to demonstrate this significance will be pursued under the study.

Program Outline

There are many aspects to the study of sand transport in the nearshore environment, some of which are well understood and others which have not been considered in existing models. Topics which must be individually studied in order to understand the overall process and will become areas of investigation in the NSTS include:

1. CHARACTERIZATION OF THE FORCING FUNCTION:

A. Relate the three-dimensional velocity field produced by shoaling and breaking waves on a straight coastline to the directional wave spectrum.

B. The three-dimensional velocity field produced by tides along a straight coastline.

C. The interactions between incident waves, other wave modes, wind and tidal and other currents which are important to sediment transport.

2. CHARACTERIZATION OF THE RESPONSE FUNCTION:

A. Bed load and suspended load of sediment as functions of sediment characteristics for various combinations of unidirectional and oscillatory flows.

B. On-offshore sediment transport and beach profiles, resulting from the effects of waves, winds and currents.

3. DEVELOP USEFUL MODELS:

A. Engineering models for two-dimensional sediment transport based upon the simplified engineering measurements and the predictive model described below.

B. Predictive models for sediment movement in various nearshore zones as functions of the velocity field models for straight coastlines.

C. Simplified, affordable engineering measurement schemes for characterizing the significant attributes of the forcing function.

It is contemplated that intensive study of the above individual topics be through a number of parallel, coordinated investigations, culminating in field experiments, carried out by scientists of proven ability in each specialty as schematically shown in Figure 1. It is expected that as the results of the individual investigations become known they will be incorporated into an overall predictive model for the transport of sand, and compared to existing field data. After synthesis of ideas into a coherent model, large scale field experiments will be designed for extensive field testing along the coasts of the United States. These field experiments will be extremely valuable in their own right, providing the quantitative measurements so sorely needed, and conspicuously absent.

Completion of these experiments will refine the physical sediment transport model so that it can be utilized as an engineering sediment transport model through the use of affordable engineering measurement schemes which characterize the velocity field sufficiently to allow reasonable predictions of transport. The engineering sediment transport model will be the final product of the National Sediment Transport Study and can then be applied by coastal engineers to the solution of sediment management problems. The schedule and budget for performing these tasks are contained in the following section.

The proposed National Sediment Transport Study is a logical research activity for Sea Grant sponsorship since it complements many research projects presently funded by Sea Grant. Figure 1 also shows the interrelationship of certain typical projects presently funded by Sea Grant and the proposed NSTS. As can be seen, these studies do not overlap any part of the NSTS but provide needed input to the proposed study at critical points during its completion. This type of contribution will be essential to the success of the study.

Schedule and Budget for the Tasks

The topics listed in the preceding section can be arranged within a series of specific tasks that fit the capabilities of investigating teams. Figure 2 shows the task designation that will be followed in this program. Each task will be addressed by a proposal, and will be the responsibility of a particular investigator or team. The program is based upon a normal program year of November to October. The 1976-77 year is nominally assumed to begin in March 1977 and end in October 1977.

The schedule and program budgets by task are shown in Figure 2. The schedule and the annual costs associated with it are predicated on an ideal arrangement with no limit on the availability of funds. If these funding levels cannot be maintained, the program schedule will be slipped accordingly. The detailed objectives of each task are contained in Table I.

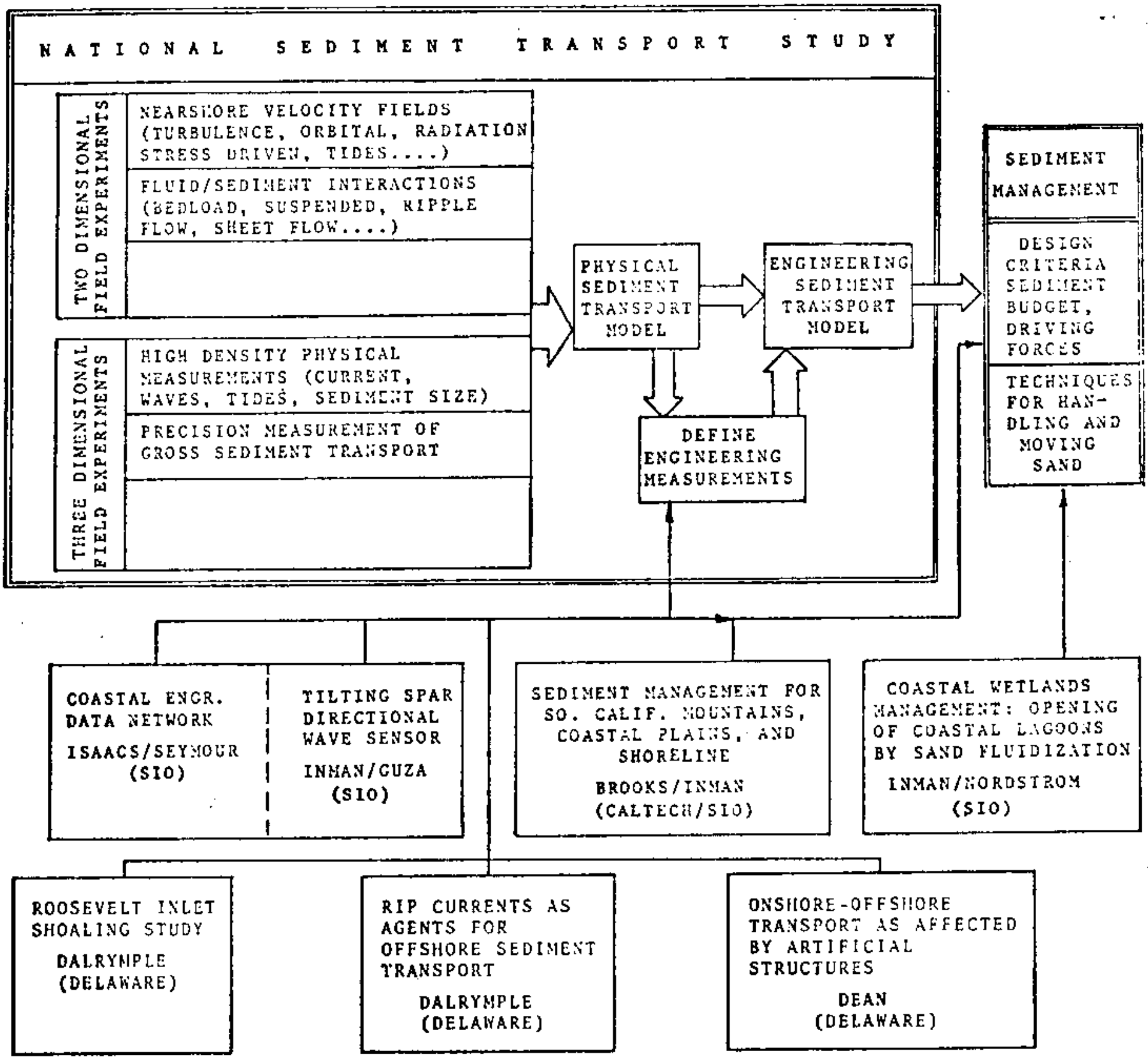


Figure 1. Organization of the National Sediment Transport Study and relationships with certain Sea Grant Projects for 1976-77.

FIGURE 2

TASK SCHEDULE AND BUDGET FOR THE NATIONAL SEDIMENT TRANSPORT STUDY

Major Area	Task Designator	Task Title	1976-77	1977-78	1978-79	1979-80
1 Characterize wave and velocity fields in and near the surf zone (forcing function)	1A	Field measurement of surf zone energetics	$ 64K	$ 80K		
	1B	Field measurement of rip currents		50	$ 55K	
	1C	Characterization of tidal currents			55	
	1D	Effects of wind and other factors on the forcing functions			55	
	1E	Development of a simplified engineering model for the forcing functions		20	35	
2 Characterize mechanics of sediment response	2A	Field measurements of suspended, bed load and ripple transport and development of predictive model	70	210		
	2B		50	75		
3 Characterize macroscale sediment response	3A	Field measurements of onshore-offshore transport and development of predictive models		50		
	3B	Field measurements of longshore transport using a trap		50		
	3C	Investigation of planform changes		30	33	
	3D	Development of simplified engineering model for sediment transport				$ 65K
4 Large-scale experiments	4A	Site planning	20	32		
	4B	Microscale sediment response measurement			150	150
	4C	Macroscale sediment response measurement			*	*
	4D	Velocity field measurement			120	120
	4E	Profile investigations			50	50
	4F	Experiment management, data synthesis and model confirmation			100	100
5 Program management	5A	Preparation of survey papers and final engineering textbook containing findings				150
	5B	Steering committee activities, workshops, seminars	11	18	20	25
		Totals	$215K	$615K	$673K	$660K

*Assumed to be provided by cooperating agencies. Otherwise, an increase in program costs will result for these years.

TABLE I

TASK OBJECTIVE STATEMENTS

Task	Task Title	Program Year(s)	Objectives
1A	Field measurement of surf zone energetics	76-78	1. Develop reliable wave and velocity sensors for use across the surf zone. 2. Characterize radiation and Reynolds stresses as functions of offshore location and sea surface and velocity measurements. 3. Construct an engineering model of the spatial variation of surface elevation and horizontal velocity across the surf zone.
1B	Field measurement of rip currents	77-79	1. Measure the velocity field associated with rip currents under a variety of wave climates in conjunction with Task 1A. 2. Develop a predictive relationship to characterize a rip current structure from a given wave climate. 3. Characterize the two-dimensional forcing function resulting from rip currents.
1C	Characterization of tidal currents	78-79	1. Measure the nearbottom longshore velocities at tidal frequencies along straight coastlines across the nearshore and through the surf zone under a variety of tide ranges. 2. Separate the current fraction attributable to the tide wave from that produced by internal waves at tidal frequencies by considering the coherence of long-term measurements at various depths.

Task	Task Title	Program Year(s)	Objectives
1C	(Continued)		3. Characterize the tidal contribution to longshore currents near the bottom as a function of distance offshore and the tidal range and type.
1D	Effects of wind and other factors on the forcing functions	78-79	1. Determine the importance of wind as a) a contribution to the forcing function, and b) a modifier of the wave and breaker field. 2. Determine the importance of interactions between the tidal elevation and the nearshore velocity field produced by waves, particularly on beaches with substantial bar structure.
1E	Development of a simplified engineering model for the forcing functions	77-79	1. Develop a simplified function, involving deep-water wave characteristics plus tides, winds or other factors found to be critical in other investigations, to characterize the forcing function for purposes of making engineering estimates. 2. Determine an affordable system of measuring this function. 3. Test the method using data sets from other tasks.
2A/B	Field measurements of suspended, bed load and ripple transport and development of predictive model	76-78	1. Design, develop and field evaluate sensors for measuring suspended and bedload transport through the surf zone. 2. Measure sediment transport simultaneously with the measurement of the forcing functions in Task 1A to provide a data base for predictive models.

Task	Task Title	Program Year(s)	Objectives
3A	Field measurements of onshore-offshore transport and development of predictive models	77-78	1. Measure the changes in profile from the beach to the bar using high resolution techniques that can be employed during severe storms, during episodes of both erosion and accretion. 2. Characterize the onshore-offshore sediment transport relationships occurring during both high stress and low stress regimes using velocity field measurements by others.
3B	Field measurements of longshore transport using a trap	77-78	1. Utilizing an effective trap, measure the net longshore transport and the forcing function, using the simplified measurement scheme developed by others. 2. Evaluate the trap effectiveness and estimate the probable error in measuring sediment transport.
3C	Investigation of Planform changes	77-79	1. Determine the interactions between periodic small-scale (order of wave length) planform variations and the velocity field. 2. Determine the interactions between large-scale periodic planform variations and the velocity field. 3. Characterize the significant interactions and their possible effects on sediment transport.
3D	Development of simplified engineering model for sediment transport	79-80	1. Utilizing the data available and the findings from the other tasks, develop an engineering predictive model for relating three-dimensional sediment transport to the simplified model for the forcing function and to other parameters found to be significant.

Task	Task Title	Program Year(s)	Objectives
4A	Site planning	76-78	1. Provide assessment of various locations and structures suitable for large-scale field experiments. 2. Recommend six candidate sites and the associated methodologies for field measurement of longshore transport rates. 3. Develop improved sampling techniques for tracer studies.
4B	Microscale sediment response measurement	78-80	1. Provide measurements of sediment transport through the surf zone to test the predictive model during each major field experiment.
4C	Macroscale sediment response measurement	78-80	1. Measure the net accumulation with time of sediment in an effective trap at the site of each major experiment. 2. Evaluate trap effectiveness and assess the probability of measuring the actual transport.
4D	Velocity field measurement	78-80	1. Provide forcing function measurements through the surf zone in each major field experiment. 2. Verify the engineering model for characterizing the forcing function from simple measurements.
4E	Profile investigations	78-80	1. Measure profiles updrift of the trap near site of the wave field measurements. Use precision, all-weather system to provide accurate onshore-offshore measurements under all conditions during major field experiments. 2. Refine predictive relationships derived in Task 3A using data from these sites.

Task	Task Title	Program Year(s)	Objectives
4F	Experiment management, data synthesis and model confirmation	78-80	1. Provide the overall scientific and technical management for a large-scale major field experiment with many investigators. 2. Synthesize the data inputs from each investigator into coherent data summaries, and an overall experiment report. 3. Confirm the engineering model from the results of the experiment and recommend improvements to the model.
5A	Preparation of survey papers and final engineering textbook containing findings	79-80	1. Prepare comprehensive survey papers covering the NSTS effort. 2. Under the general editorship of the Steering Committee, prepare chapters for an engineering, user-oriented text setting forth the findings of the program.
5B	Steering Committee activities, workshops, seminars	76-80	1. Provide overall planning coordination and guidance to the program. 2. Disseminate data through workshops, symposia and publications. 3. Prepare an engineering text describing the results of the study.

DATA CABLES

Meredith H. Sessions
Scripps Institution of Oceanography

Introduction:

Many applications in the near shore ocean environment require the connection of various sensors to gather and sensors to recording or telemetery packages remotely located from these sensors. Most of these installations require the transmission of electrical power and data signals. Recent trends in environmental monitoring programs additionally require long term reliable operation of the cables forming these systems in the ocean environment. Most off-the-shelf cables that have been used in these applications were not originally designed for long term underwater application, and therefore have failed to perform reliably.

Recent Trends:

Numerous new plastic materials have become available and the capability for their inclusion in cable manufacturing has rapidly progressed in recent times. This allows the user of cables to specify the mix of materials best suited for his individual application. It is possible by careful design and material selection to configure a cable which is less expensive than a standard off-the-shelf cable not well suited to the requirement, but which otherwise would be used. Most designs are trade offs which are optimized for the design application, and considerable performance improvements are available by controlling these optimizations. For instance an underwater cable suffers minimum water absorption when subjected to the hydrostatic environment if the interstices are completely filled. This can easily be accomplished for a low cost by filling each segment with a depolymerized rubber compound during manufacturing.

Many cables require moderate strength to withstand stress of installation, wave inducted motions, and ocean currents. These types of applications usually resort to the use of an armored type construction with a steel alloy outer cover. Experience with these types cable indicate that while they have considerable tensile strength ,they are quite prone to corrosion and abrasion by sand and rocky structures. If such a cable has a jacket of tough plastic coated over the steel armour, abrasion and corrosion resistance are increased many times. The addition of this jacket is usually only a small part of the cable cost.

As part of many cable systems, sensors must be connected to the cable with an underwater connector. Experience has shown that these connectors and their attachments to the cable cause many of the system failures in the field. It is quite possible to eliminate many of these connections by integrating sensors into the cable assembly. We have for instance, had a temperature sensing array fabricated with the sensors built into the cable assembly and jacketed with a plastic cover eliminating all the external break out. This design yielded a solution to a long standing problem and increased field life from one to two months in the ocean to well over one year. More recently we have been able to successfully mold a pressure sensor directly on the end of a specially designed cable eliminating all connectors. Freedom of material selection in this cable allowed the selection of outer jacket material to be compatible with high quality molding compound suitable for this application.

The selection of the proper cable manufacturing facilities is equally as important as the cable design. Due to the variation in design philosophy from company to company, and the machinery available, considerable differences exists in the capability of various manufacturers to respond to a particular job. A careful survey to discover manufacturers capable of producing your design is necessary. Consultation with manufacturing engineers can result in significant savings by adapting your specifications to their capability. We recently discovered that a parallel lay armour jacket could be applied to a cable in place of the traditional twisted or braided lay armour with an overall cable cost savings of about 30%. This was due to the fact that it was possible to avoid using the largest slow moving braider machine in the plant to produce the same cable assembly, thereby realizing a substantial cost savings.

New materials are constantly being brought out of the laboratory and into field applications. One should be aware of industry trends in the application of these new materials and experience gained with specific applications. The U.S. Navy has maintained several large development programs for a number of years which have resulted in the application of new materials such as kevlar to replace steel in large high strength underwater applications. These programs have resulted in the development of manufacturing capability and experience which is now available to the general community.

Summary

Each cable application should be reviewed independently of off-the-shelf standard designs. Once requirements are specified, an optimized design for that application should be determined.

Consultation with design engineers from various manufacturers will reveal individual capability to utilize new materials and fabricate specific designs economically. By utilizing these techniques, it is often possible to achieve both significant performance increases and cost reductions in many undersea cable applications.

CRITICAL CHOICES FOR OCEANOGRAPHIC DATA ACQUISITION AND TELEMETRY SYSTEMS

S. Rankowitz

Instrumentation Division
Brookhaven National Laboratory
Upton, New York 11973

Introduction

The engineering of a comprehensive data acquisition system between remote measuring stations and a central collection station (Fig. 1) is based on critical selection of options following a realistic consideration of the constraints imposed by the particular application. The appropriate partitioning of functions within the system and a sensible selection of techniques are governed primarily by these constraints and their inevitable economic consequences.

Basic System Constraints and Considerations

The basic system considerations and constraints for an oceanographic data acquisition system are:

1. Remote Station

   Acceptable energy consumption rate.

   Spectral range of analog sensors.

   Noise amplitude and spectrum superimposed on analog sensor outputs.

   Physical, mechanical restrictions.

---

*This research carried out under the auspices of the Energy Research and Development Administration: Contract No. EY-76-C-02-0016.

ENVIRONMENTAL DATA ACQUISITION AND TELEMETRY SYSTEM

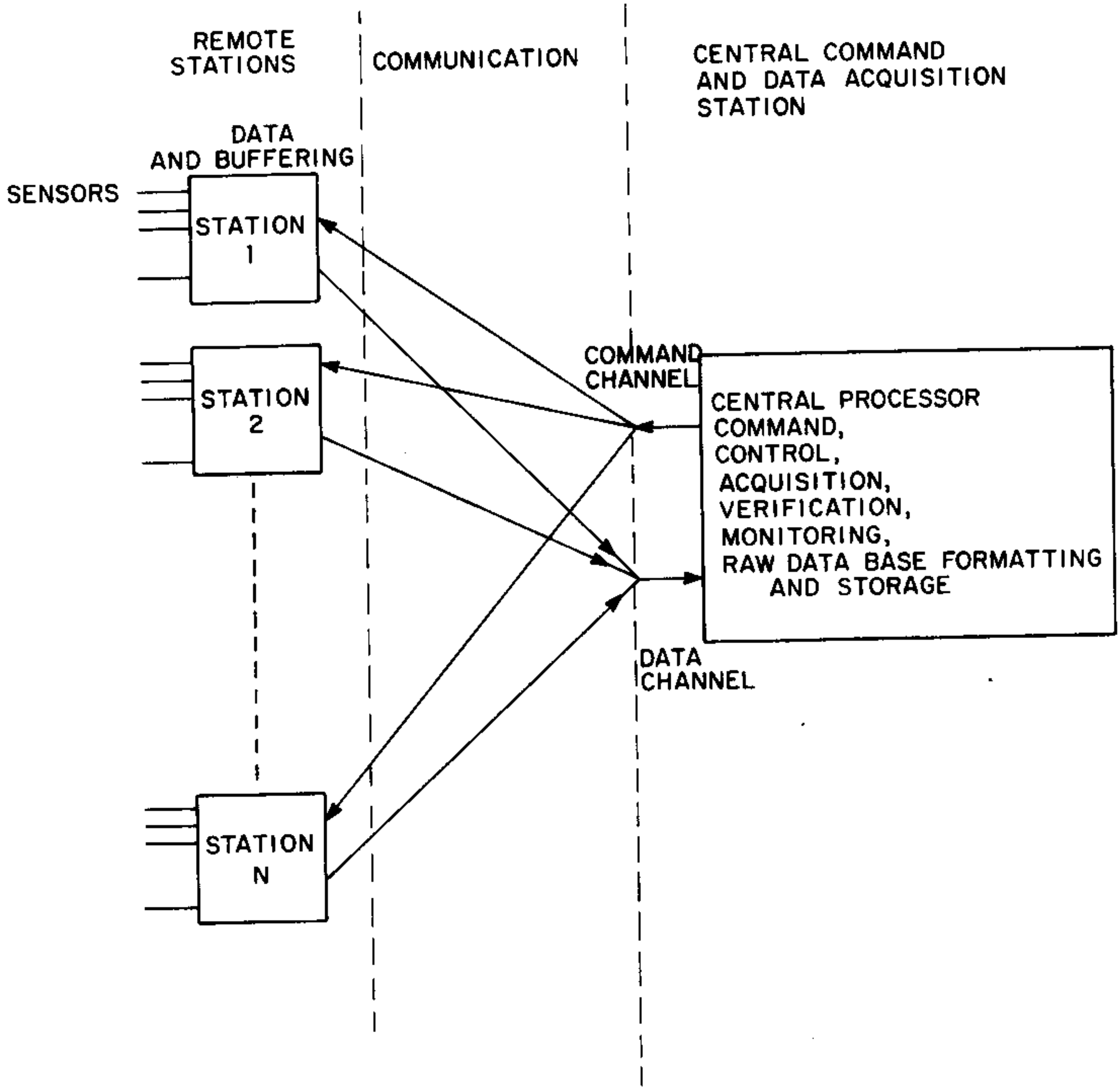


FIGURE 1

2. Communication System

   Distance between source and destination of measured information.

   Spectral bandwidth required for information conveyance.

   Spurious signal or noise interference expected.

   Channel availability in geographic region.

3. Central Station

   Focus on primary objective to verify incoming data.

   Generate and store raw data base of verified data in format convenient for later manipulation or calculation.

   Do data manipulation, calculations in a different processor with transported data base.

All transducer analog signals must be converted to digital representation for processing,calculations and storage. The physical difficulties, manpower, time, shipping requirements, and related costs involved in servicing remote stations mandate efficient management of remote station energy sources. Energy conservation is the dominant consideration in determining the location of analog to digital format conversion. Analog signal transmission requires continuous transmission of each transducer signal requiring continuous operation of the largest power consuming component in the remote system (transmitter). There are other important disadvantages resulting from continuous analog signal transmission, e.g., superposition of additional noise in the communication channel, reducing the signal to noise ratio at the signal processor, DC drift problems, separate communications channel or subchannel requirements for each transducer. The duty cycle of the transmitter needs to be minimized if the cost of operating the remote stations and obtaining data over long time periods can be managed. Digitizing the analog signals in the remote station as close to the transducer as possible is necessary to provide maximum signal to noise ratio before conversion and to generate a format suitable for in-situ storage. Low power consuming digital integrated circuit memory devices are widely available at continually reduced costs. Large digital memories for remote station storage applications provide a reasonable technique for temporary local data storage between transmission periods.

Processing of Analog Signals

The following questions require careful study before selecting appropriate digitizing techniques for the specifiç application. The choice of incorrect techniques for a given set of requirements cannot be compensated at later stages in the system.

1. What is the information needed from sensors?
2. What is the spectral or transient nature of required information from the sensors?
3. What is the amplitude and spectrum of spurious signals and noise superimposed on the required information signal?
4. What is the most suitable conversion technique for the required information?

Specifying the information needed at the earliest phase in the development of the system is essential to the proper selection of the technique. Selecting a technique to provide more information than actually needed seriously impacts every following stage in the system with additional unnecessary cost, (local and remote memory capacity processing, bandwidth requirements, etc.) as well as the possibility of introducing distortion into the information region of actual interest.

The analog to digital conversion technique selection is based on the spectral composition of the required information and the spurious signals and noise to be rejected. Low bandwidth information conversion uses integrating techniques which

DISTINGUISHING A/D FEATURES

PARAMETER	VOLTAGE TO FREQ.	DUAL SLOPE	SUCCESSIVE APPROX.	WILKINSON
1. Spectral composition of desired information	< 10 Hz	< 50 Hz	> 50 Hz	> 50 KHz
2. Inherent noise rejection	Yes	Yes	No	No
3. Additional noise rejection at certain frequencies	No	Yes	No	No
4. Integral linearity	Good	Good	Good	Good
5. Differential linearity	Good	Good	Poor*	Good
6. Monotonicity	Good	Good	Poor*	Good

*Poor means extra design care and cost required to overcome inherent technique difficulties.

TABLE I

inherently have the greatest noise rejection capability. Voltage to frequency converters and dual slope converters fall in this category. High bandwidth information conversion techniques such as successive approximation and Wilkinson techniques inherently have no noise rejection capability. The significant or distinguishing features of these converters are compared in Table 1.

The spectral composition regions are intended for broad comparison and should not be interpreted as precise boundaries. The dual slope technique has additional substantial noise rejection capabilities at uniquely specified frequencies (Fig. 2). It can be used to provide extraordinary rejection by integrating the signal for an integral number of periods of the desired rejection frequency. Integral linearity is the maximum deviation of the output from a straight line from zero to maximum output. Differential linearity is the variation between adjacent output conversion codes for equal analog signal steps. Monotonicity is the degree to which the conversion technique produces a unique code for every value of analog input. Because of the inherent comparison boundaries in the successive approximation technique, exceptional design care with consequent expense are required to reduce missing codes to acceptable levels for many applications. (Fig. 3).

Basic Converter Techniques

Voltage to Frequency Converter (Fig. 4)

The signal voltage (V_{in}) charges C linearly. At a fixed comparator reference (V reference) voltage the discharge timer switches a constant discharge current to dump C for a precisely controlled time (T_c). The output consists of a pulse train whose frequency is proportional to the signal voltage in. Ultimate accuracies depend on stable timing and references. The pulse train is counted in a scaler for precisely controlled times. Since the scaler digital output can be buffer stored, essentially no time gaps are introduced in the measuring interval. Thus, voltage to frequency technique can be used for continuous measurement and integration with

INTEGRATING ANALOG CONVERSION – NOISE REJECTION

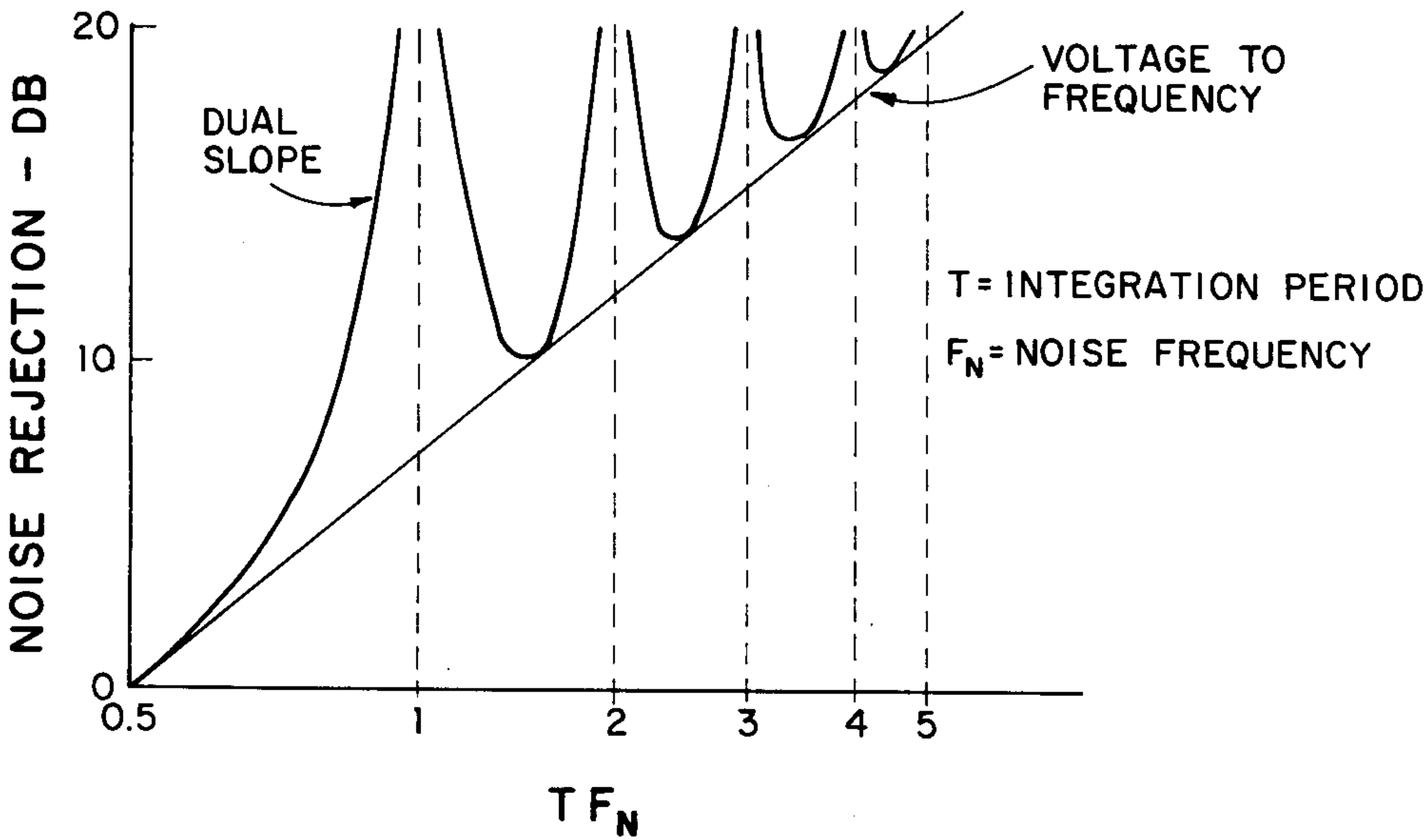


FIGURE 2

ANALOG CONVERSION LINEARITY AND MONOTONICITY COMPARISON

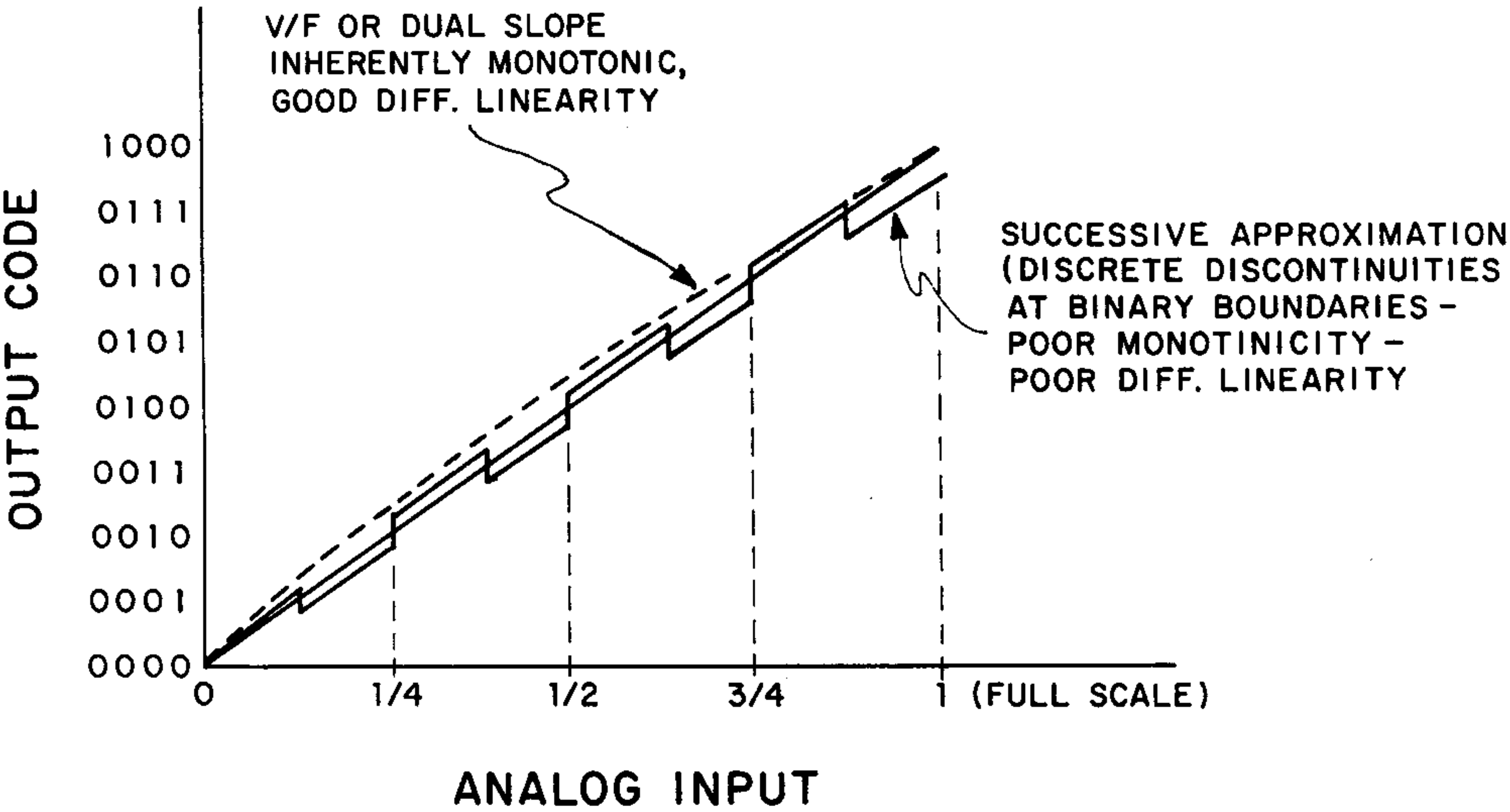


FIGURE 3

BASIC VOLTAGE TO FREQUENCY CONVERTER

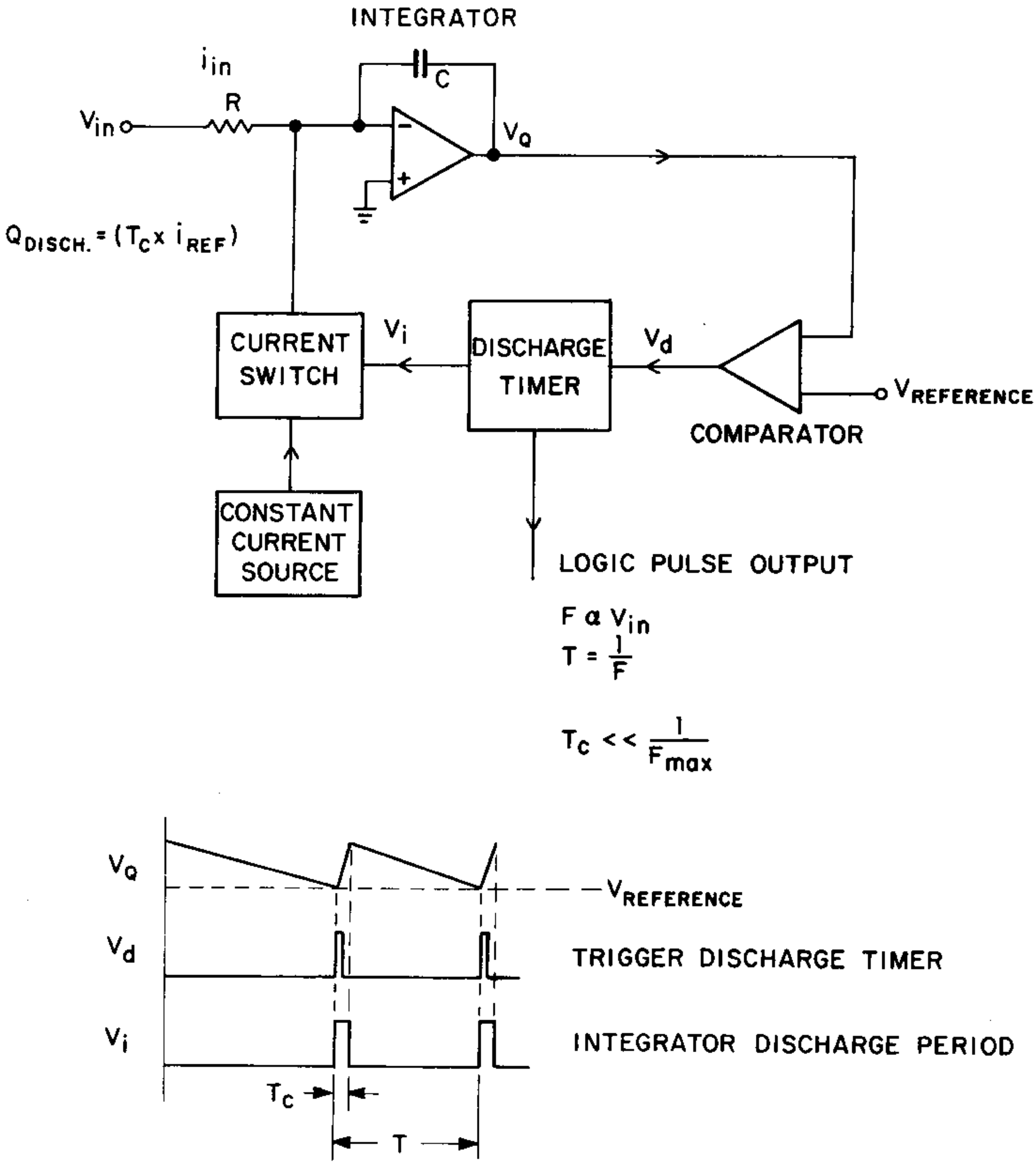


FIGURE 4

any selected measuring interval. At the same time there is no excessive amount of digital data stored,only that required and measured by choise of the integrating interval.

In many cases, the spectral region of interest or need is much lower than the spectral output region of the sensor. Continuous integration of the sensor output signal for periods determined by the actual need produces data which includes the entire history of the sensor output. The voltage to frequency conversion technique, with rapid transfer of counts to buffer memory storage provides the most effective and simple means to provide a continuous and complete history of the analog signal and only the spectral region needed to meet the measurement objective. The effect of noise superimposed on the sensor output is optimally reduced with this technique[1].

Dual Slope Conversion (Fig. 5)

The signal voltage is switched to a linear integrator for a precisely controlled time, T_I. The integrator is then switched to a constant reference voltage source until the integrator is discharged, T_D. The discharge interval is precisely measured, using the same clock which controlled T_I. The discharge interval timer count is proportional to the integrated value of the signal for the sample period T_I. If there is a noise source at a particular frequency, setting integration period T_I precisely equal to the period of the unwanted frequency results in integration over a complete period of the noise frequency. This should theoretically result in infinite rejection of this frequency. The rejection characteristic is shown in Fig. 2.

Successive Approximation Conversion

The successive approximation converter compares successively, at fixed time intervals, the instantaneous value of the input signal voltage with a binary stepped

DUAL SLOPE CONVERSION

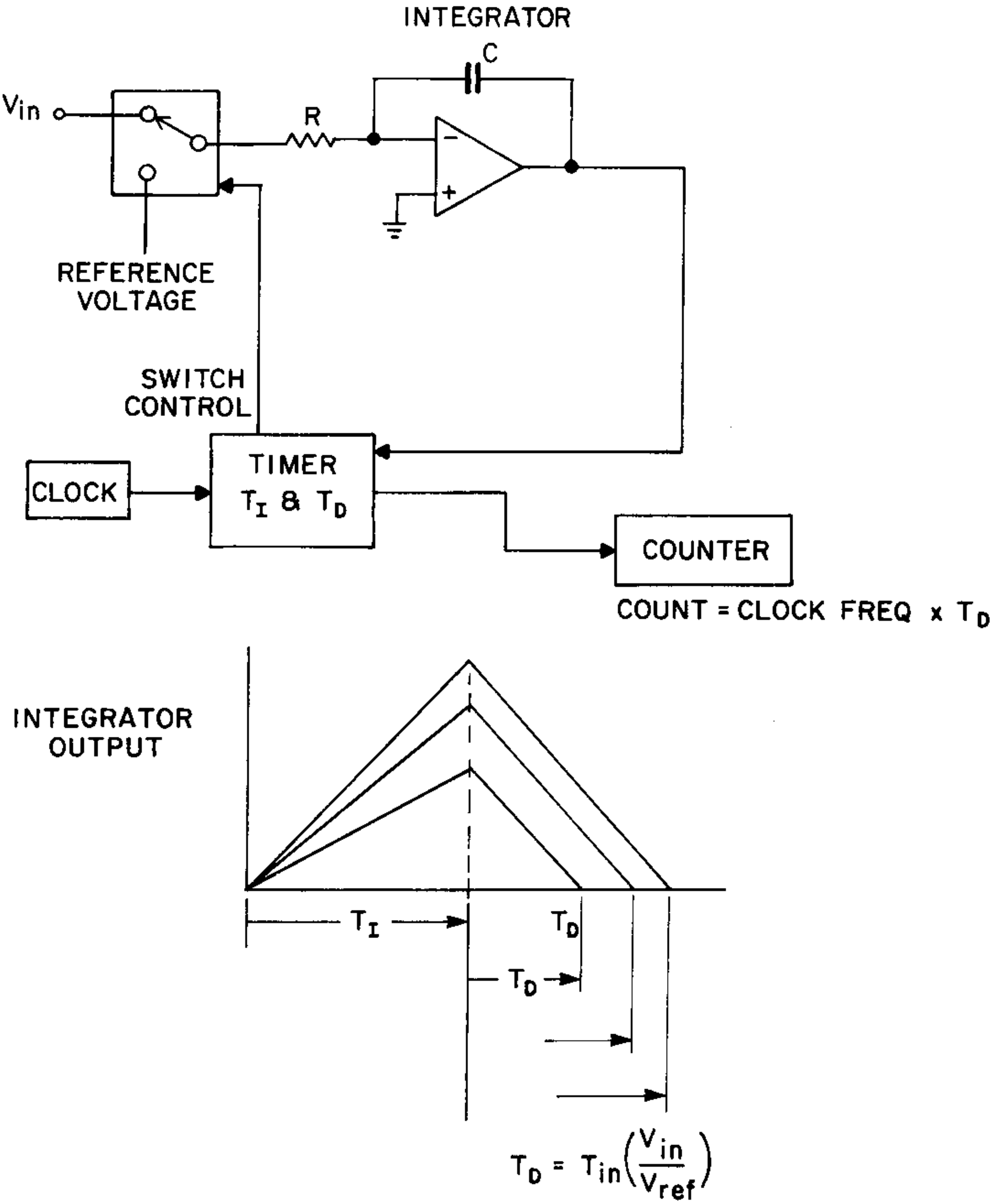


FIGURE 5

reference voltage. The comparison at each binary place value results in the setting of a 1 or 0 for that place value. The binary information for each place value is stored in a shift register whose shifts coincide with each comparison. This process continues from highest order to the lowest order binary step comparison for the specified number of bits. The contents of the shift register at the end of conversion is the binary weighted value of the input analog signal.

If the input signal is not held constant, then the effective time of the sample is ambiguous as well as the actual instantaneous point of sampling. If the rate of change of analog signal is significantly high, then the analog signal must be sampled, stored, and held constant for the duration of the conversion process. The conversions consist of samples of signals pulse noise, with no inherent noise rejection capabilities. This technique should only be used where the higher order spectral components of the analog signal are desired. Other means are required to reduce the effect of superimposed noise. The instantaneous noise within each sample will be added to the sample. The sampling and filtering requirements will be discussed in a following section.

Wilkinson Conversion

This technique is used for digitizing or converting instantaneous analog signal to digital form by sampling and storing the value of the analog value in a holding capacitor. The capacitor is then discharged with a constant current. The end of conversion is determined by comparison with a reference voltage. The discharge interval is measured precisely with a clock, which also synchronizes the start and stop of the conversion process. This technique results in conversions with inherently good monotonicity and differential linearity because it does not depend on discrete time comparisons and the quality of a reference digital

SUCCESSIVE APPROXIMATION CONVERSION

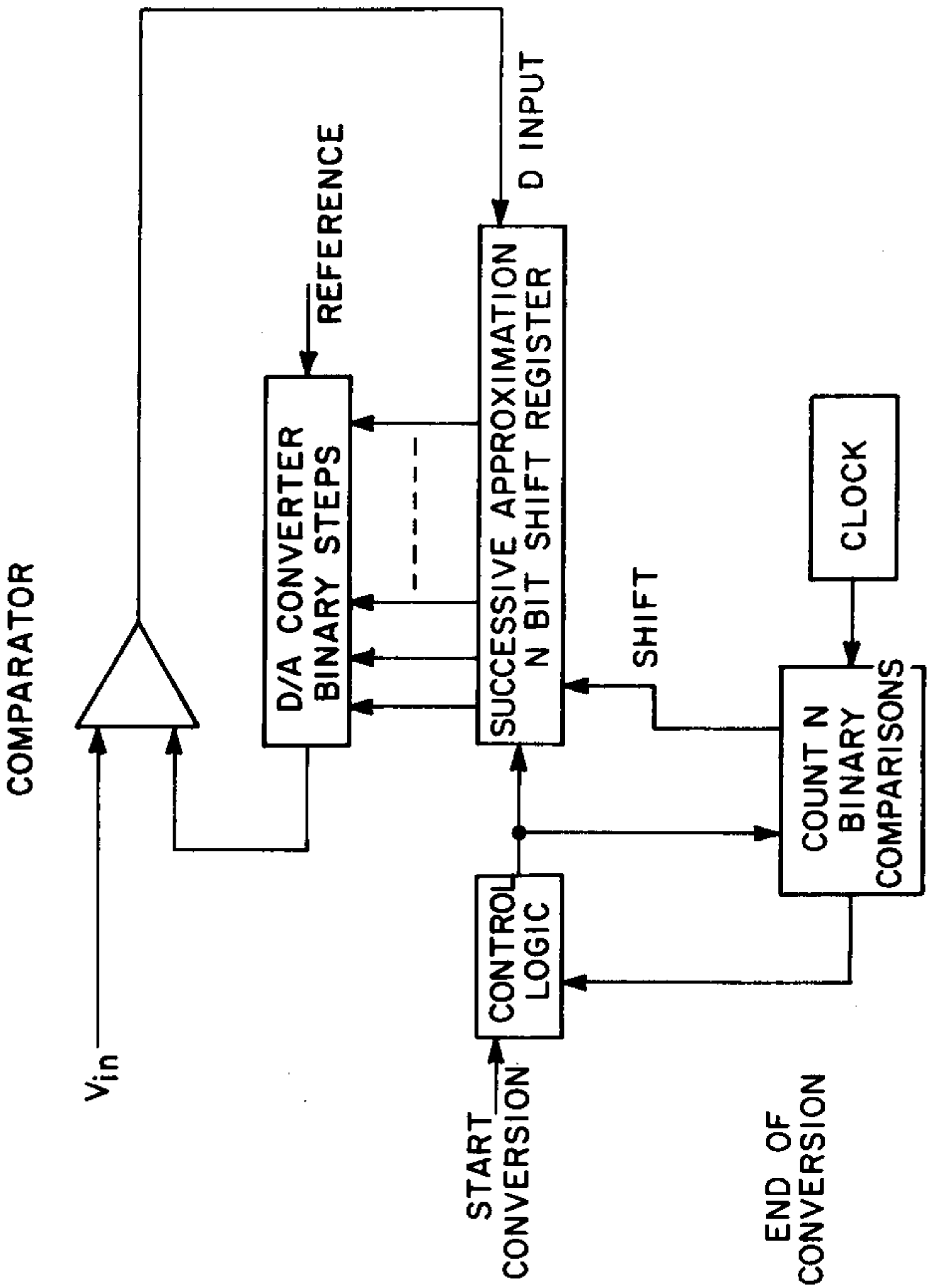


FIGURE 6

to analog converter. However, in order to produce fast conversions, the timing clock frequency must be very high. The circuitry is much more complex than for the successive approximation method. However, when fast sampling or pulse amplitude measurement and sorting is required, differential linearity is critical, and this technique must be used.

Sampling Considerations

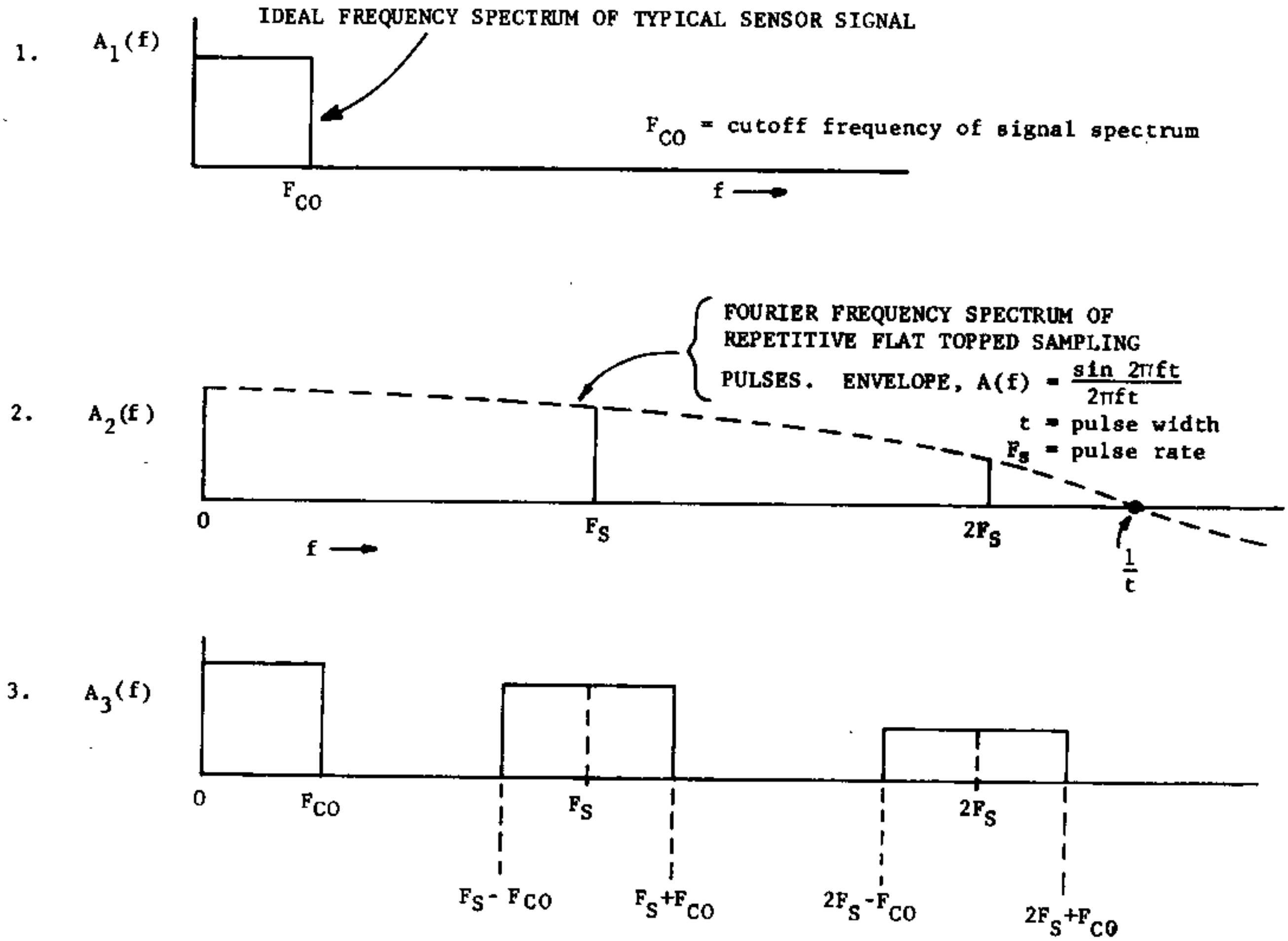
Basic and practical sampling considerations must be understood in order to transfer the required information. Distortion contributed by incorrect use of sampling cannot be determined or removed at a later stage in the system. A sensor dynamic analog signal in the time domain can be represented by a Fourier Spectrum in the frequency domain. The Fourier frequency components are related to the rates of change in the time varying signal. The greater the rates of change in the analog signal, the higher will be the frequency components in its Fourier Spectrum.

Figure 7-1 illustrates the frequency spectrum of a fictitious sensor where the highest frequency required to represent the dynamic analog signal is F_{CO}. The sampling process consists of modulation of the sensor analog signal with another signal, a periodic series of pulses with a finite width (t) and repetition rate, F_S. The Fourier frequency spectrum of the sampling signal is represented in Fig. 7-2. It is composed of a series of multiples of the sampling repetition frequency whose relative amplitudes are determined by the function,

$$A(f) = \frac{\sin 2\pi\ ft}{2\pi\ ft}$$

The amplitude envelope of the sampling pulse spectrum first reaches zero at $F = \frac{1}{t}$. The effect of sampling is to multiply the analog signal by the sampling pulse train. The resultant waveform has a spectrum consisting of the original analog signal spectrum (width F_{CO}) and sum and difference bands of the original spectrum centered

BASIC THEORETICAL SAMPLING CONSIDERATIONS



SPECTRUM $A_3(f) = \left[A_1(f)\right] \times \left[A_2(f)\right]$

LOWEST IDEAL SAMPLING RATE WHEN $F_{CO} = F_S - F_{CO}$

$$\boxed{F_S = 2F_{CO}}$$

EQUI-SPACED DATA WITH AT LEAST 2 POINTS PER CYCLE OF HIGHEST FREQUENCY REQUIRED FOR BAND LIMITED FUNCTIONS

FIGURE 7

at integral multiples of the sampling frequency (Fig. 7-3). Recovery of the information in the original signal requires elimination or filtering of the spurious upper bands. If an ideal low pass filter were used to remove the upper bands, the original information could be retrieved without modification.

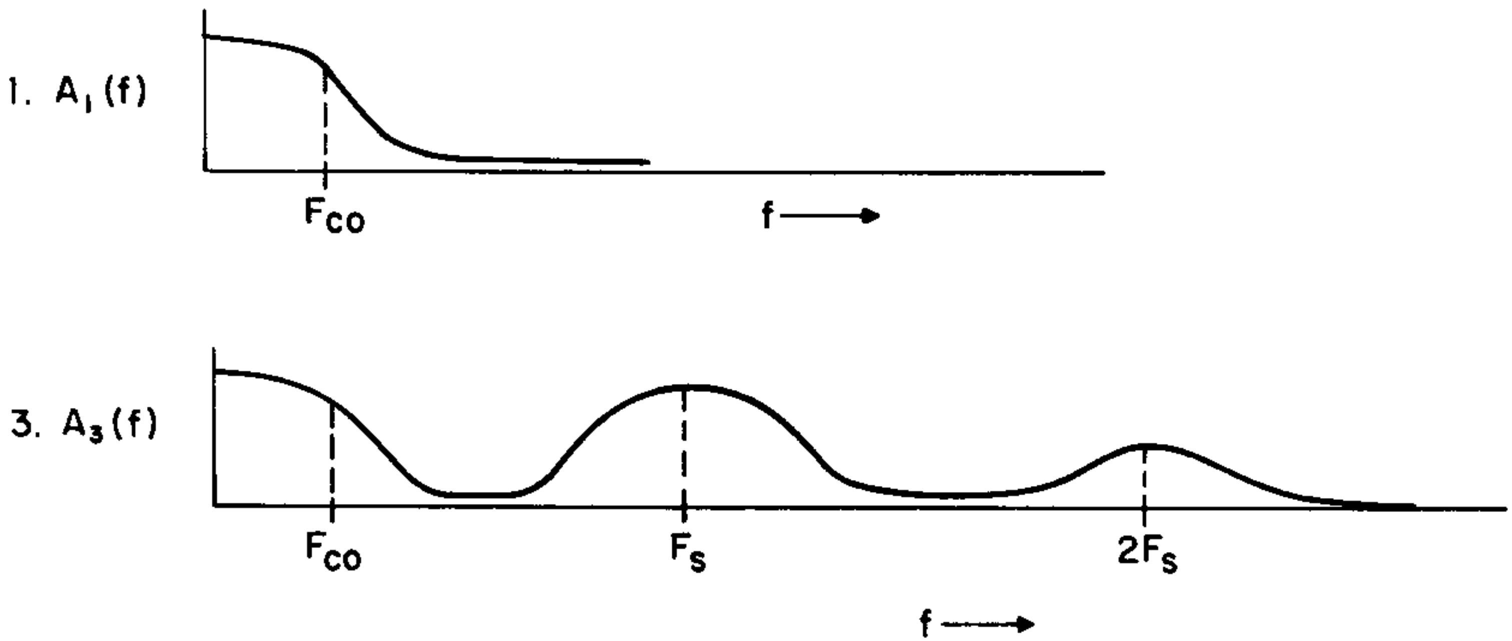
If the sampling frequency is insufficiently greater than the highest frequency in the analog signal spectrum, the low frequency end of the spectrum centered at F_S which contains the high frequency information of the original spectrum would fold over into the original spectrum. The folded signals could not be separated from the original signal and would constitute an undetectable distortion of the original signal. The folded frequency components added to the original signal band generate "aliases" in the original signal spectrum. The boundary condition for minimum separation for ideal filters and absolute cutoff frequencies is

$$F_S = 2F_{CO}$$

The minimum practical sampling rate is determined by first deciding the spectral content that is essential to preserve the required information sought from the sensor and then selecting the filter characteristic to insure that higher components are rapidly attenuated.

However, real practical filters, and the signal spectra of real signals combined with noise are never ideal low pass functions. Figure 8 represents a typical realistic spectral situation. Practically, the complete elimination of foldover or aliasing is impossible. The real choice to be made by the experimenter is what degree of distortion is acceptable within the constraints of information required and the increasing economic costs for incremental reduction of the distortion through filtering and higher sampling rates. However, one A to D conversion technique, voltage to frequency, is inherently effective in reducing aliasing with its 6 db per octave attenuation internal filter. Sampling or measuring interval changes are permitted, even during an experiment, without introducing aliasing

PRACTICAL SAMPLING CONSIDERATIONS



MINIMUM PRACTICAL SAMPLING RATE DETERMINED BY:

1. KNOWLEDGE OF ANALOG SIGNAL AND NOISE SPECTRUM.
2. ATTENUATION CHARACTERISTIC OF ANALOG SIGNAL FILTER.

FIGURE 8

Digitized Information Transmission

Data Encoding or Formatting Techniques

Transmission of the data from buffer memory in the remote station to the Central Data Collection Station via a communications link requires selection of an encoding scheme which permits: 1) transmission of serial digital data information as rapidly as available channel bandwidth allows; 2) easy combination at the source and decommutation after reception of the serial digital data stream into data and coherent clocking for any combination of data patterns; 3) detection after reception of any combination of errors caused by noise between encoding and decoding of the serial digital data.

The fastest and most efficient serial encoding system for digitizing systems employs binary format transferred bit and block synchronously. The data, organized as blocks are transferred synchronously as blocks with synchronization required only at the bit level and block level. The data is organized into groups or blocks containing a preassigned number of words with a fixed number of binary formatted bits per word. A unique block or frame synchronizing word is inserted at the start of each block before serial bit transfer of the entire block at a constant bit clocking rate. Successive blocks are transferred with no time gaps in the bit synchronization. The next block synchronizing word follows immediately after the last word of the previous block. There are no start or stop identifying indicators of individual data words within the block. Each complete block ends with a unique checking word such as a check sum or cyclic redundancy word inserted at the transmission end. At the receiving station each type can be used to detect certain combinations or errors introduced after transmission. This technique wastes nq precious transmitter time with unnecessary code bits, start-stop bits, time gaps, or individual word error checking bits, e.g., word parity.

A less efficient, but commonly used encoding scheme encodes the data into USASCII standard 8 bit character assignments. The data is transmitted bit and character synchronous. Filling binary coded data into ASCII without producing unwanted control characters allows six bits for data, one pre-assigned to eliminate control characters and one for parity. Data transmissions must be 33% longer in order to transfer the same information as in the block technique. However, individual character errors can be identified.

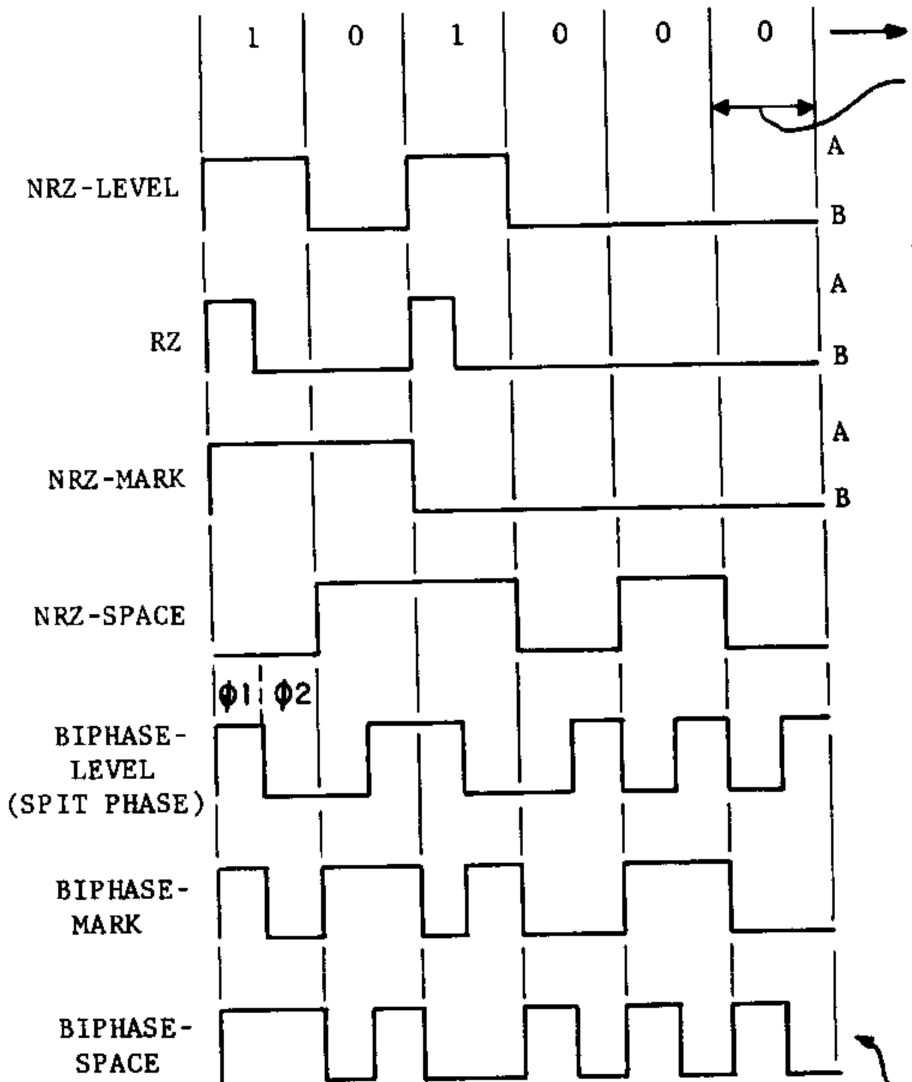
The least efficient technique, and one that is only used when all the data is not readily available at transmission time is bit synchronous, character asynchronous transmission. This encoding scheme adds a uniquely identifying character start and stop bit to the ASCII eight bit character. Thus, each character with six bits of binary data information requires ten bits to transfer in addition to waiting time between characters. There is no justification for ever using this scheme in an energy constrained telemetry system.

Binary Pulse Code Modulation Techniques

Figure 9 shows a comparison of the most popular modulation techniques in current use for serial time transfer of binary information. They are synchronously timed streams of pulses containing binary data and clocking information. They differ in: 1) communication channel bandwidth required for a given data transfer rate; 2) ease of maintenance of bit synchronization for different data patterns, and consequently the ability of the bit demodulator to extract synchronized clock and data streams from the composite serial pulsed modulation stream.

Figure 10 shows a comparison of the information spectrum for the types of modulation illustrated in Figure 9 as a function of frequency, expressed as fractions of the BIT RATE. The same binary information sequency is represented by vastly different pulse modulation patterns with differing bandwidth requirements. Different rates of transitions are generated by the codes for a given data pattern.

COMPARISON OF SERIAL BINARY INFORMATION MODULATION CODES (PULSE CODE MODULATION)



NRZ-LEVEL: "1" = LEVEL A; "0" = LEVEL B

RZ: "1" = ½ BIT WIDE PULSE A; "0" = NO PULSE

NRZ-MARK: "1" = LEVEL CHANGE; "0" = NO LEVEL CHANGE

NRZ-SPACE: "1" = NO LEVEL CHANGE; "0" = LEVEL CHANGE

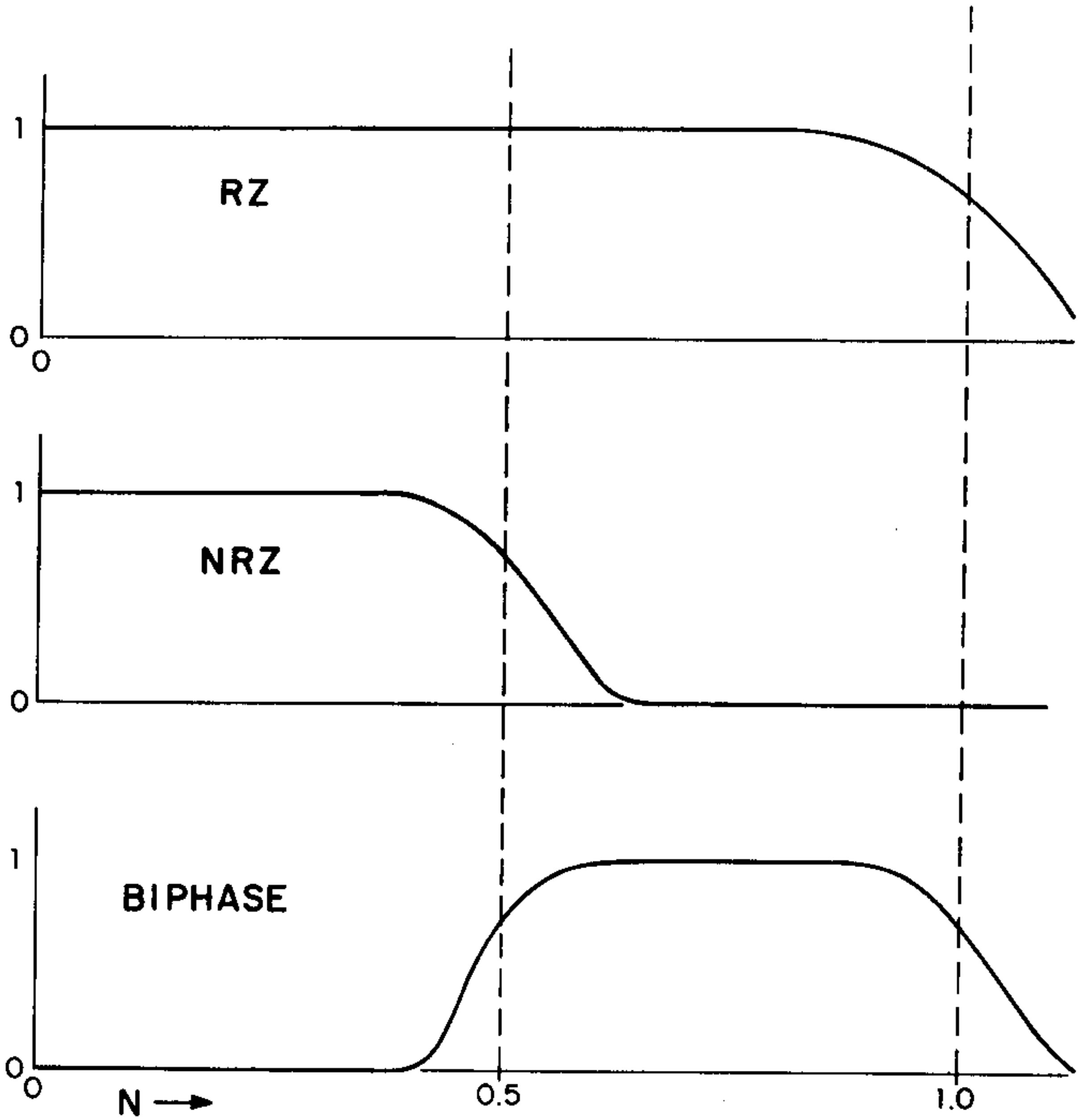
BIPHASE-LEVEL (SPIT PHASE): (MANCHESTER 11 + 180°) "1" = ½ BIT PULSE PHASE 1; "0" = ½ " " PHASE 2

BIPHASE-MARK: (MANCHESTER 1) TRANSITION AT START EVERY BIT PERIOD; "1" = SECOND TRANSITION - ½ BIT; "0" = NO SECOND TRANSITION

BIPHASE-SPACE: TRANSITION AT START EVERY BIT PERIOD; "1" = NO SECOND TRANSITION; "0" = SECOND TRANSITION - ½ BIT

FIGURE 9

COMPARISON OF INFORMATION SPECTRUM FOR SERIAL CODES



FREQUENCY = N x BIT RATE

FIGURE 10

Return to zero, (RZ) and non-return to zero, (NRZ), can produce patterns down to DC with no transitions for a constant pattern of all zeros or ones. The BIPHASE codes guarantee a minimum transition rate of one per two data bit cycles for data that does not change up to a maximum of one for each cycle for alternating zeros and ones. The BIPHASE codes guarantee a minimum transition density of 50% for the worst data pattern (constant data), and therefore, is the most satisfactory pattern for locking phase locked loops to the coherent clock frequency with minimum jitter. The RZ and NRZ patterns must specify a minimum transition density or data pattern for which it can maintain synchronization.

The detection properties of the NRZ-LEVEL and BIPHASE-LEVEL are superior to their respective "MARK" and "SPACE" codes. The "LEVEL" codes contain all the bit information within one bit time period so that the detector requires no memory between adjacent bits. In the "MARK" and "SPACE" codes the detection relies on detecting changes of data level. An error in any bit causes the adjacent bit to be in error so that errors occur in pairs.

The information bandwidths of NRZ and BIPHASE codes (Fig. 10) are equal for the same bit rate except that BIPHASE is a bandpass code with no low frequency components. However, the upper frequency required for adjacent channel separation is the same as required for RZ. BIPHASE requires no DC coupled circuits in the signal processing, eliminating errors caused by circuit DC drifts. The bit synchronizer should filter out low frequency noise from the BIPHASE signal.

Since the BIPHASE code has an inherent phase ambiguity, preamble patterns of alternating zeros and ones must precede the actual data to establish the desired phase relationship in the detector.

If the bandwidth can be made available for the bit rate desired, the BIPHASE system permits lower jitter and greater noise rejection capability with widely varying transition patterns than the NRZ codes. The BIPHASE LEVEL code is recommended since it provides additional detection advantage over the MARK and SPACE BIPHASE codes.

Communication Links

Line of Sight Links

The choice of the appropriate communication link for the telemetry system depends primarily on the distance between remote stations and the central station. If the distances are within line of sight for the greatest practical antenna heights, then a VHF or UHF communication link provides the most desireable solution if frequency allocation can be obtained in the region where it is needed. Procuring frequency allocations for telemetry is likely to be a formidable task since VHF is now practically eliminated and UHF telemetry allocations are generally limited to certain restricted bands above 1 GHz. If the allocation can be obtained, then the experimenter can maintain control over all aspects of the system.

Long Distance Links - HF

For long distances beyond line of sight, until recently, the traditional solution employed the HF communication band (3-30 MHz). This portion of the spectrum propagates via reflections from the ionosphere. The propagation characteristics for frequencies within this range vary seasonally and diurnally making them unreliable for automated telemetry communication. HF is no longer a serious option for long distance telemetry communication systems.

Line of Sight Links - Synchronous Satellites

For environmental measurement systems, a government owned and operated synchronous satellite communication system is available as an operational telemetry tool. The system, employs east and west synchronous geostationary satellites over the equator at 75° W and 135° W longitude with backup at 105° W, at altitudes providing nearly complete hemispheric coverage. The Geostationary Operational Environmental Satellite (GOES) System is operated by the National Environmental Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce exclusively for environmental research or monitoring purposes.

The GOES System provides other services for NOAA, but the communication link available for users approved by NESS with no costs charged for the service provides the most attractive and powerful tool available today for long distance environmental research programs in the United States. The system provides for time shared channels as well as interrogated operations. The user is responsible for all costs relating to his platforms and retrieval of the raw data from NESS via land lines.

There are no domestic communication satellite communication systems now readily available for scientific use without extraordinary expense.

<u>Meteor Burst</u>

An interesting experimental developmental system soon to undergo testing is a system built by Western Union for the Soil Conservation Service of the Department of Agriculture. The system uses reflections of low VHF (40 to 100 MHz) from meteor trails in the ionosphere. The system depends on statistical understanding and predictability of meteor ionization trails. Messages or data are transmitted at very high rates in response to polling the remote station when propagation conditions are satisfactory for that station. System delays vary with seasonal meteor characteristic ionosphere penetration patterns. Optimization of the polling sequences depend on the control station prediction of ionization patterns based on their statistical history.

Recommendation for Future Telemetry Communications

The choice of communication links for future telemetry systems is divided into clear cut choices based on distance. Short distance line of sight links using UHF channels (if available) provide the simplest, lowest cost system entirely under the control of the experimenter. For distances beyond line of sight, GOES provides the best option available for environmental systems in the foreseeable future. Developments being sponsored by some government agencies employing domestic communication satellites may provide a distant future alternative. However, at this time there is no alternative to the GOES system.

References

1. D. G. Dimmler, S. Rankowitz, D. W. Huszagh, and J.Scott; A Controllable Real-Time Data Collection System for Coastal Oceanography. Presented at Conference OCEANS '76, 13-15 September, 1976. Published in Proceedings of the same, p. 148.

RECORDING SYSTEMS

R. L. LOWE

Scripps Institution
of Oceanography

Introduction:

Three types of data recording systems are considered for the NSTS data acquisition problem. Because of the vast quantity of data anticipated, only magnetic tape based systems are being considered. The three basic recording techniques for storing raw data are frequency modulation (FM), pulse code modulation (PCM), and digital computer type. Each of these systems has inherent advantages and disadvantages which must be considered before a system can be selected.

FM-FM Recording System:

An FM-FM recording system may be briefly described as a frequency-division multiplex of frequency-modulated subcarriers recorded via a frequency-modulated carrier. The FM-FM system provides a simple, flexible technique for recording a number of analog channels via a common carrier with good frequency response and reasonable accuracy. Since data values are encoded in the form of subcarrier frequencies, the system is insensitive to level changes in the tape recorder and frequency response down to DC is obtained. Because there is a one-to-one correspondence between subcarriers and data channels, the system can be optimized for the number and type of data channels.

Standards have been set up to provide a set of fixed frequencies, thereby making a versatile and flexible but thoroughly proven series of channel configurations available to the user. This standardization also results in the easy availability of components.

FM systems are normally employed when these performance levels are desired:

Accuracy	0.5% >2%
Data Bandwidth	D.C. to 10 K Hz
No. of Data Channels	Less than 30

Telemetering of the data over RF links is readily accomplished using FM/FM techniques. If telemetry is used, the bulk of the equipment can be centrally located leaving small relatively inexpensive equipment exposed to the environment of the field site.

The cost of this type of system sufficient for the NSTS needs would be in the order of $100,000. The individual sub-subsystem elements are generally available and no development would be necessary.

PCM Recording System:

Basically, a PCM (pulse code modulation) system is a time-multiplexed sampled-data system in which the values of the input data channel samples are expressed in digital (usually binary) form. Thus a sequence of "1" and "0" is generated which is grouped in binary "words" describing the value of the particular channel at the instant of sampling. This sequence of "1" and "0" is normally further encoded into a format known as bi-phase which is then recorded using direct electronic recording onto magnetic tape.

The primary advantages of PCM include the capability for handling both digital and analog data, flexibility as to the number of channels and sampling rate, capability of recording data of arbitrary accuracy with little or no degradation, and generally superior characteristics of information efficiency.

PCM systems are generally used when these performance levels are desired:

Accuracy	Greater than 0.1% (10 bit binary)
Data Type	Digital and Analog
No. of Channels	$\geq$ 10

The PCM technique is compatible with RF data links. For systems which require telemetry on small PCM, encoding packages need to be in the field. Therefore, the more expensive equipment can be housed in a protected area.

The cost of this type of system would be on the order of $100,000 or $200,000. All components of the system are either commercially available or have been developed here at Scripps.

Computer Based System:

A computer (either a mini or micro computer) based data record system consists of a data multiplexer, analog to digital converter, standard computer tape recorder and a computer. Tapes prepared on this type of system are completely IBM compatible nine-track tapes. The advantages of the system are complete versatility as to number of channels and sampling rates. These parameters are under program control. Tape would be directly usable for data analysis. Some processing of the data could be accomplished in real time.

This system would not be readily adaptable to telemetry. Time synchronization between various systems would not be easily accomplished.

Cost of such a system to handle up to 32 channels of data would be between $10,000 and $30,000, depending on the type of computer used.

Conclusions:

All three of the data recording techniques would be adequate for the NSTS program. It would appear that PCM might have some advantages; namely, it can handle a large number of channels with high accuracy and requires little hardware at the field site.

VELOCITY MEASUREMENT

Clinton D. Winant
Scripps Institution of Oceanography

For current measurements which require a frequency response up to one Hertz and a spatial resolution on the order of 1 meter, a number of instruments exist which are characterized by good linearity and angular response.

The list of current meters developed by oceanographers for such measurements is too long for an inclusive review. We limit ourselves to those current meters which independently sense two orthogonal components of the velocity vector. In addition, we require that the instruments have a linear response to velocity and a cosine response to the angle between the velocity vector and the orientation of each axis sensed. The obvious advantage of such current meters is their ability to average properly current fluctuations at frequencies higher than those being sampled. This has made such instruments very useful to the deep sea oceanographer, and although coastal current measurements are usually such as to resolve the highest frequency motions, the advantages of linear two-axis current meters in terms of simplicity of data reduction and calibration make them most attractive instruments.

Over the past five years, three types of instruments satisfying the requirements set forth have been introduced, and a brief summary of the characteristics of typical members of each type will be reviewed. It should be emphasized that this note is not in any way a comprehensive review of all available instruments, but rather attempts to present typical characteristics of each type of instrument.

Acoustic Travel Time Sensors:

These sensors are based on the principle that a sound wave travels between two points at a speed C+U where C is the speed of sound in water and U the component of water current in the direction of travel. Thus, if a current $\vec{U}$ exists between two acoustic transducers, such that $\vec{U}$ makes an angle Θ with $\vec{\ell}$, the vector connecting sensor 1 and sensor 2, the travel time required of a wave emanating from 1 to reach 2 is

$$T_{12} = \frac{|\vec{\ell}|}{C+|\vec{U}|\cos\Theta}$$

and the travel time from 2 to 1 is

$$T_{21} = \frac{|\overset{<}{\ell}|}{C-|\overset{<}{U}|\cos\theta} .$$

The obvious algebraic manipulations yield:

$$|\overset{<}{U}|\cos\theta = \frac{|\overset{<}{\ell}|}{2}\left(\frac{1}{T_{12}} - \frac{1}{T_{21}}\right)$$

$$C = \frac{|\overset{<}{\ell}|}{2}\left(\frac{1}{T_{12}} + \frac{1}{T_{21}}\right)$$

In spite of the algebraic simplicity, most travel time sensors are not implemented in this fashion, and for the following reasons:

(1) Obtaining reciprocal time is a cumbersome electronic transformation.

(2) The speed of sound in water, C, is usually larger by at least 3 orders of magnitude than typical currents.

Since variations in C due to temperature, salinity and pressure are relatively unimportant, the expression can be written as

$$T_{12} - T_{21} \cong 2|\overset{<}{\ell}| \frac{|\overset{>}{U}|\cos\theta}{C^2}$$

Within the constraints imposed by the assumptions, the component of the current in the direction of travel is linearly proportional to the difference in travel time.

The greatest complexity associated with these instruments concerns the accurate determination of the time difference, since the speed of sound is large, and $|\overset{<}{\ell}|$ is usually kept on the order of 10 cm. Problems have also been encountered when air bubbles and foreign matter are present in the acoustic path.

Typical calibration information kindly supplied us by Neil Brown Instruments, Inc., are shown in Figures 1 and 2. Typical accuracies are on the order of .5cm/sec with noise levels of .1cm/sec.

Electromagnetic Sensors:

These take advantage of Faraday's law which states that a conductor (sea water) moving with velocity $\vec{U}$ through a magnetic field $\vec{H}$ generates a voltage $\vec{V}$

$$\vec{V} = \overline{H} \times \vec{U}$$

The sensors generate a magnetic field $\vec{H}$ and sense voltage differences between pairs of electrodes. Thus, in the presence of a vertical magnetic field $\vec{H}$, a current $\vec{U}$ making an angle Θ with the line separating two electrodes will induce a voltage between these:

$$V_1 = |\overline{H}||\overline{U}|\sin\Theta$$

and a voltage $V_2 = |\overline{H}||\overline{U}|\cos\Theta$ between a pair or electrodes mounted orthogonally to the first pair.

The primary difficulty associated with the measurement is that the magnitude of the product of the magnetic field by the current is sensed. Thus random fluctuations in $\vec{H}$ due to variations in the earth's magnetic field, for instance, can contaminate the velocity measurement. Such problems are overcome by alternating the sign of $\vec{H}$ at a frequency large compared to that of the highest velocity fluctuation expected. Synchronous demodulation techniques are then used to recover the velocity.

Typical calibration data provided by Marsh McBirney is given in Figure 3.

Mechanical Sensors:

A mechanical current meter consisting of two orthogonal flow sensors has been developed at Scripps Institution of Oceanography by Dr. Russ E. Davis and R. Weller. Each sensor consists of a pair of fans and the rotation rate of the common shaft is given by

$$R = \alpha|\overline{U}|\cos\Theta$$

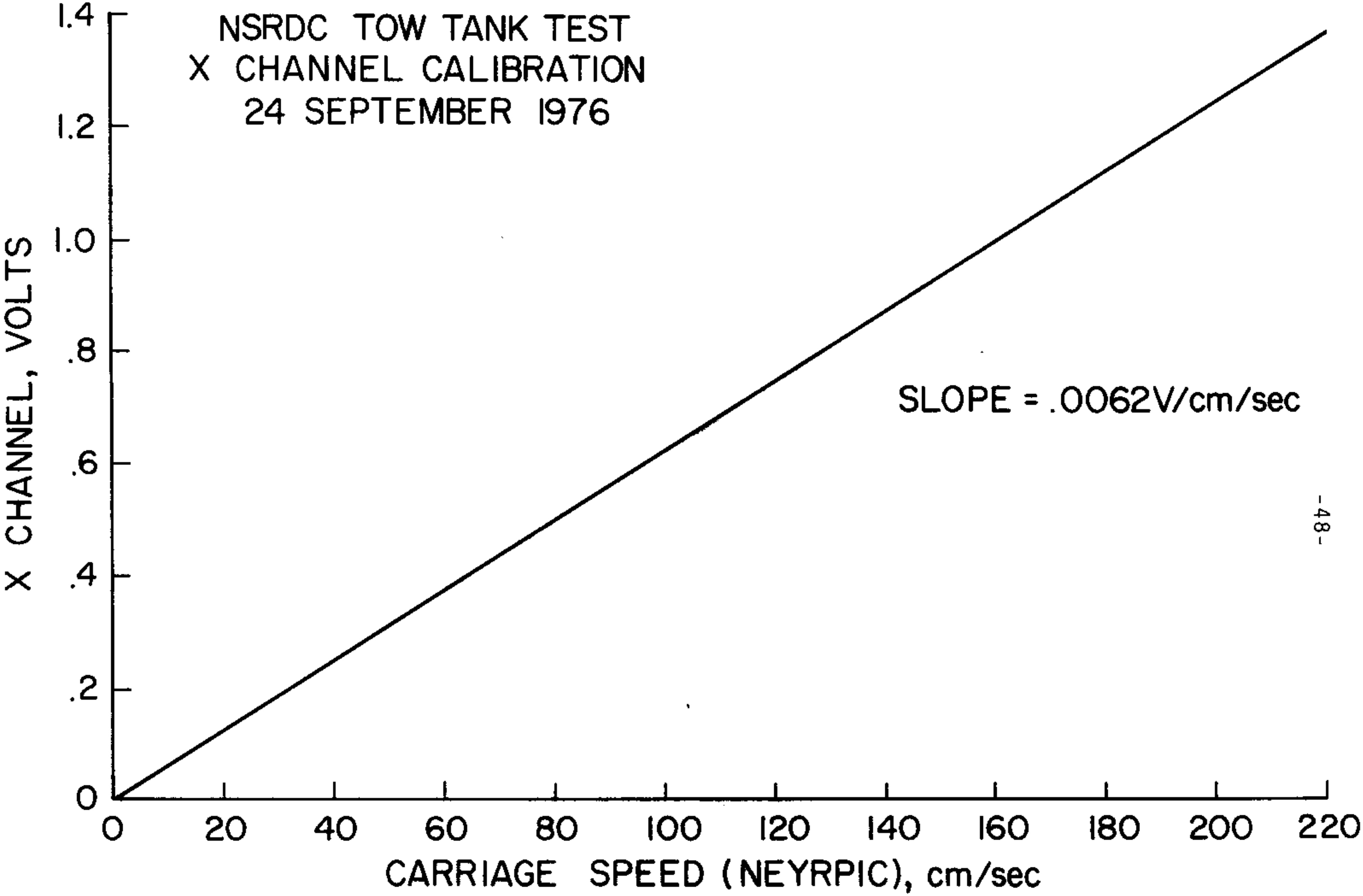
where $\overline{U}$ is the velocity of the current being measured, and Θ is the angle between the flow sensor axis and $\overline{U}$. The shaft is instrumented so that a quarter turn produces a pulse and, additionally, a signal is available indicating whether the shaft is rotating clockwise or counterclockwise. Counting pulses generated by clockwise rotation as positive and vice-versa, the number of pulses accumulated during some time interval Δt is equivalent to integrating $|\overline{U}|\cos\Theta$ over Δt and an average velocity in a direction parallel to the sensor can be deduced as

$$U = \frac{\sum_{\Delta t} \text{pulses}}{\Delta t}$$

Similarly, the other average velocity component can be obtained from the orthogonal sensor.

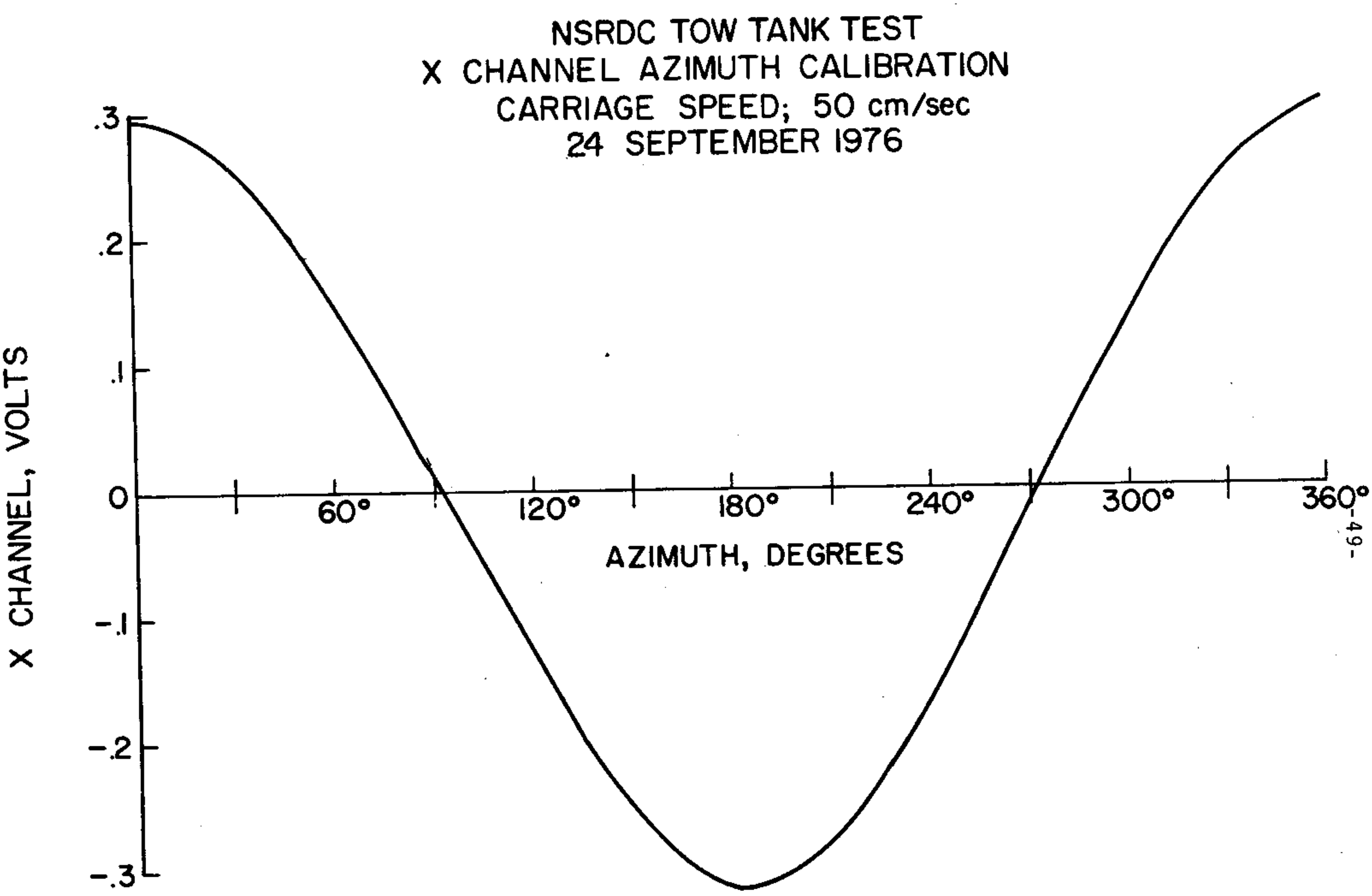
As with most mechanical sensors, limitations here occur when the fluctuations in velocity are such that the wake of the sensor interferes with the flow being sensed. Thus if the maximum fluctuating velocity is on the same order as the mean velocity one would expect the linear relation between velocity and shaft rotation to be invalid and this has been observed (R. Weller, private communication). Practially this problem limits the sensors to measuring flows with frequency less than 1Hz.

Typical linearity and angular response curves are given in Figures 4 and 5, supplied by R. Weller.



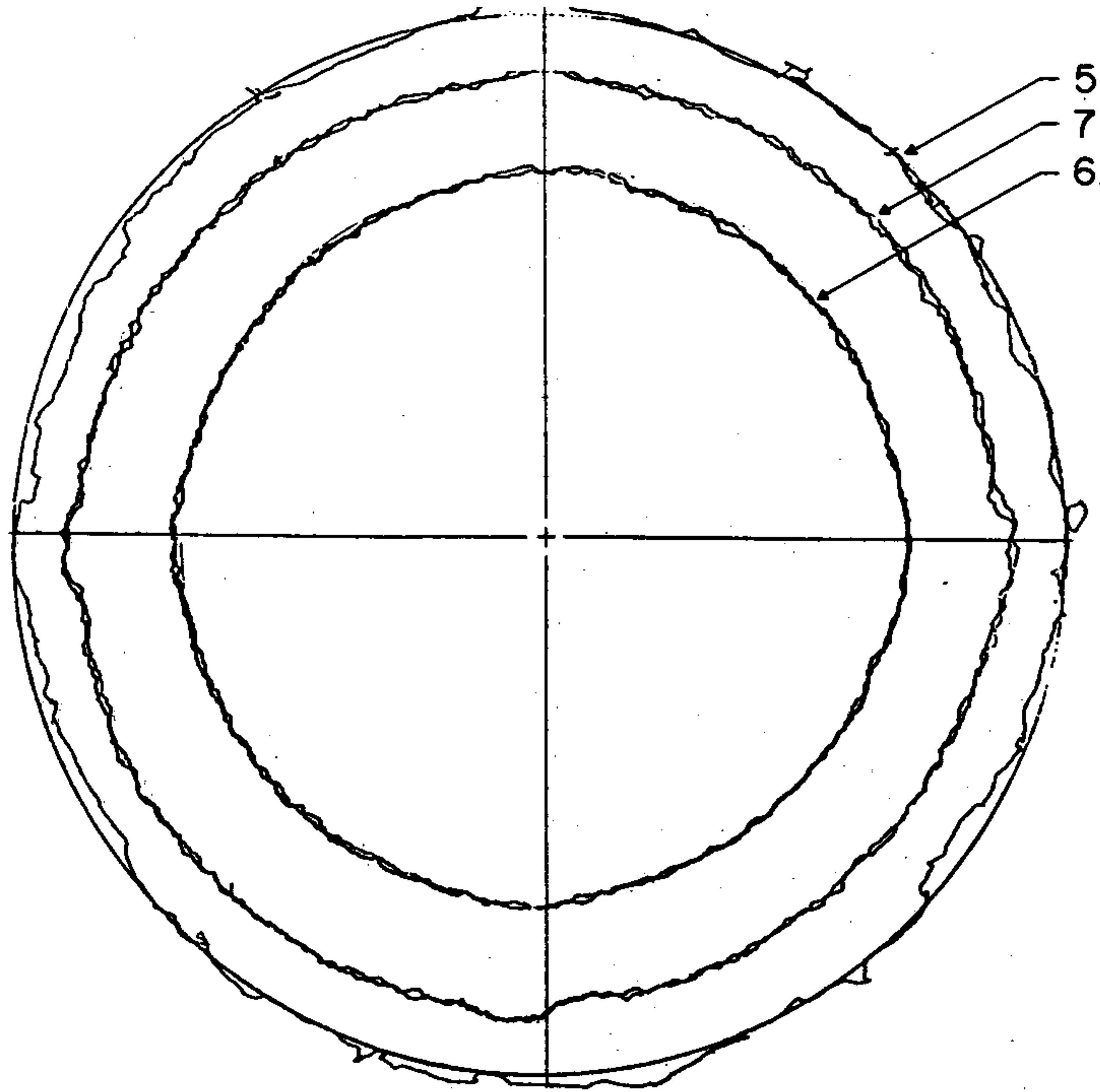
LINEARITY OF ACOUSTIC VELOCIMETER

Fig. 1



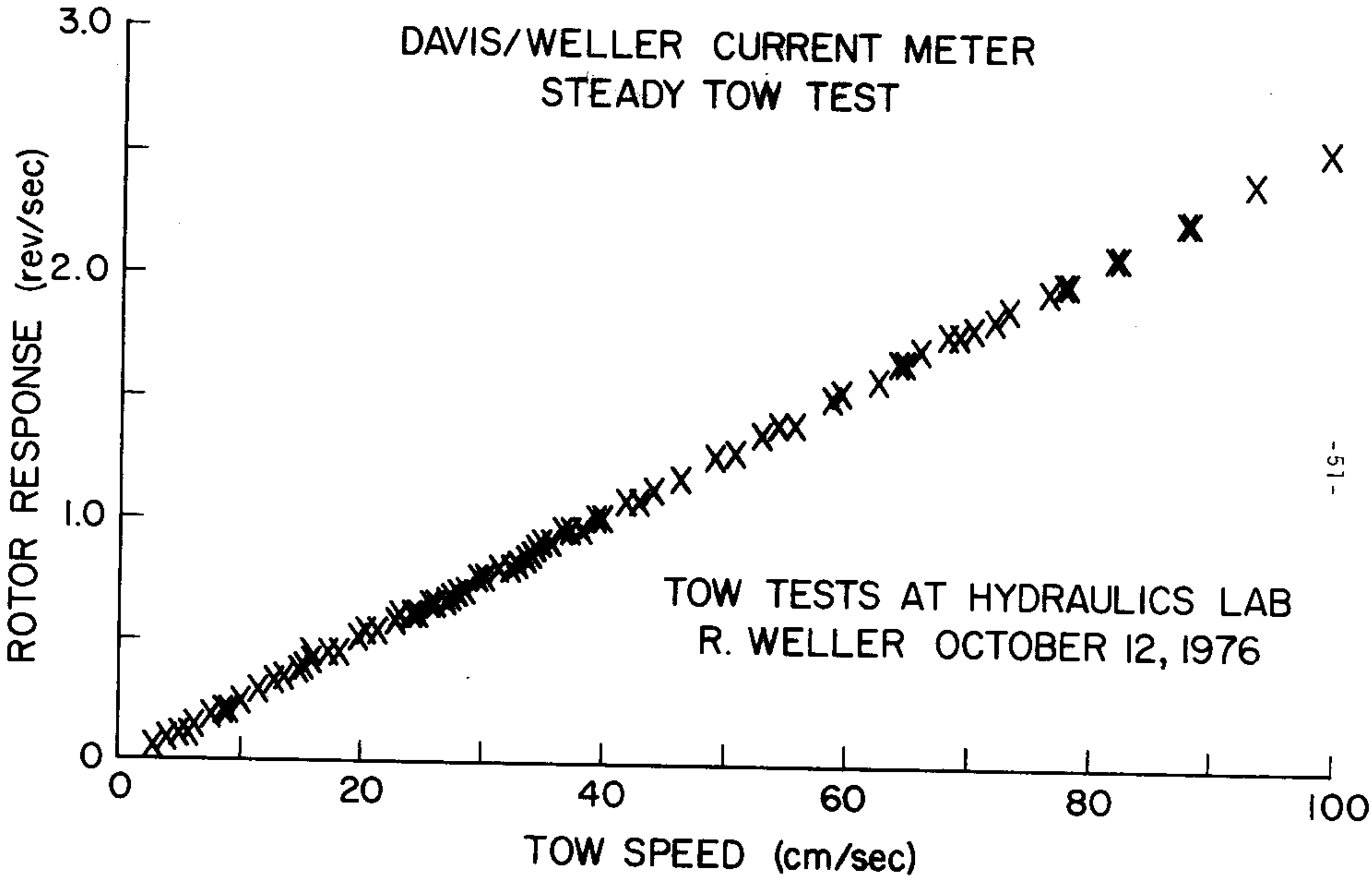
ANGULAR RESPONSE OF ACOUSTIC VELOCIMETER

Fig. 2



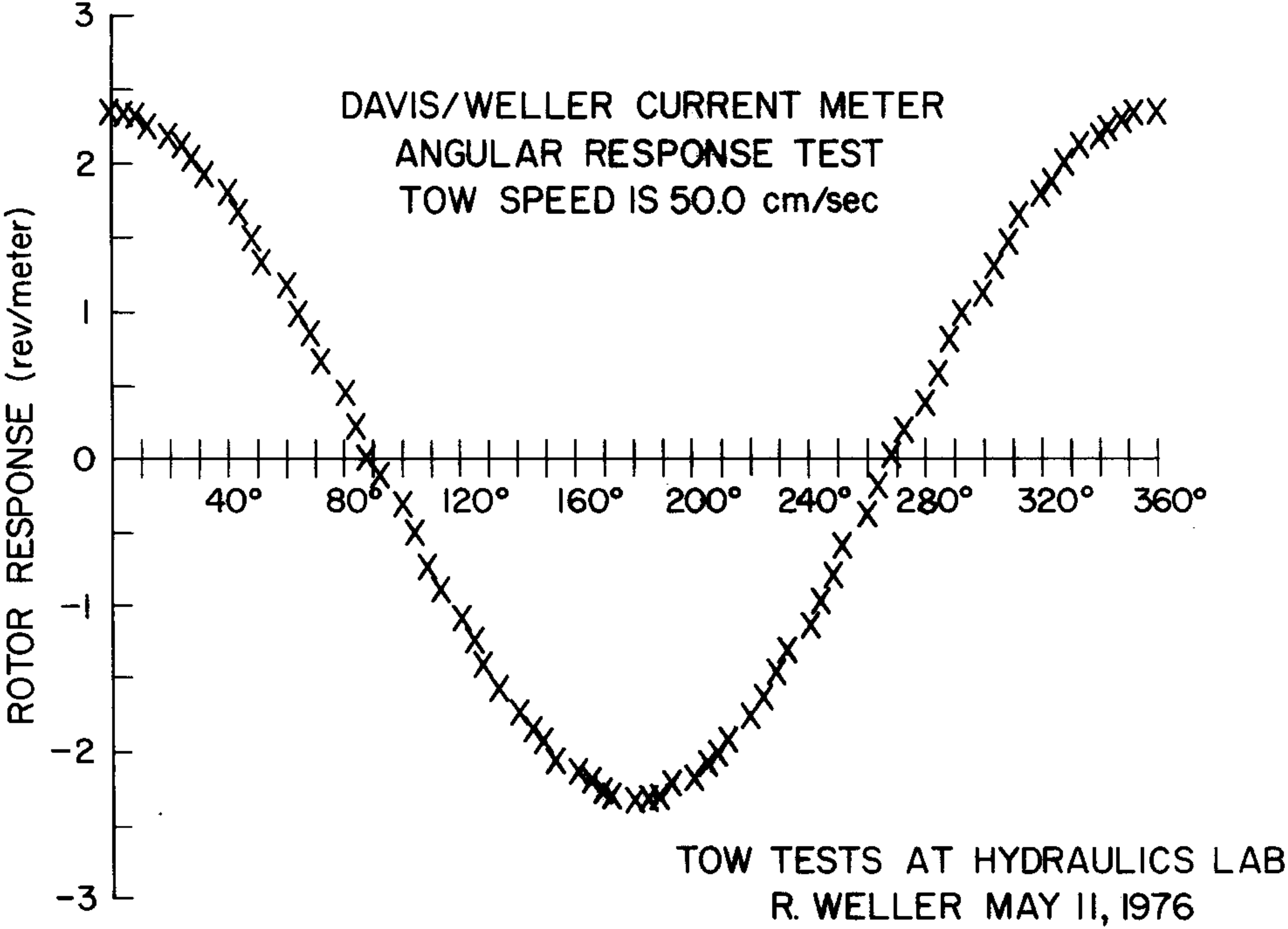
COMBINED LINEARITY AND ANGULAR RESPONSE OF ELECTROMAGNETIC VELOCIMETER

Fig. 3



LINEARITY OF MECHANICAL VELOCIMETER

Fig. 4



ANGULAR RESPONSE OF MECHANICAL VELOCIMETER

Fig. 5

WAVE SENSORS

by

Edward B. Thornton
Naval Postgraduate School
Monterey, CA 93940

A large variety of wave measuring devices based on various physical principles have evolved, including direct, indirect and remote techniques (see table 1 for a partial list). Each technique has inherent advantages and disadvantages depending upon the application. Desirable characteristics of any wave sensor should include: proper representation of the sea surface, accuracy, linearity, and ruggedness and dependability. In addition, the utility of the wave sensors is highly dependent upon the type of installation for which they can be adapted.

TABLE I Wave Sensors

- Direct Methods
  - Capacitance wave staffs
  - Resistance wave staffs
  - Inductance wave staffs
- Indirect Methods
  - Pressure
  - Acoustic (inverted fathometer)
  - Optical (laser)
  - Acceleration (wave rider buoy)
- Remote Methods
  - Radars
    - Coherent
    - Incoherent
    - Over-the-horizon
  - Optical (lasers)

Direct measures of the sea surface are intrinsically more assuring than indirect methods. Penetrating wave staffs using the principles of resistance, capacitance or inductance are popular for this reason. The disadvantages of wave staffs are that they usually require mounting on a rigid structure such as a tower or pier piling. Inaccuracies of wave staffs are due to wave own dynamic response and results in a filtering of high frequency waves. The mooring can also influence the dynamic response of the buoys. Therefore, the knowledge of the dynamic response of the combined system of the buoy and mooring system must be known so that proper conversion of acceleration to surface displacement can be made.

Remote sensing offers the advantage that the sensors can be mounted on movable platforms such as airplanes or satellite and large areas of the earth can be measured quasi-synoptically. Remote sensing techniques are based on the scattering of electro-magnetic radiation from the surface either coherently or incoherently. Early techniques utilized photography to determine surface slopes from sun glint patterns. Stereoscopic photography has been used to determine directional wave spectra although this method proved to be highly cumbersome. Laser profilometers have been used in which a narrow beam of light is used to very accurately measure the sea surface displacement from an airplane. Using this technique a wave number spectrum can be obtained very rapidly over fairly large areas. The disadvantage is that this technique requires the use of a very expensive platform. Spatial resolution is dependent upon the narrowness of the cone of light and also the distance above the sea surface. The spatial resolution determines the resolvable high frequency end of the wave number spectrum.

Radars have also been used from airplanes to measure the sea surface elevation. Radars can sense the surface coherently, which is essentially the same as taking of a picture of the sea surface, or incoherently in which the variance of the sea surface is measured over a fairly large area. Coherent scattering is based on bragg scatter off waves whose wave lengths are commensurate with the wave length of the radar. Because of limitations on the radar

The wave spectrum is increasingly filtered as the depth of the sensor placement increases. A practical limit for placement of the pressure sensors for determination of sea and swell type waves is approximately 20 m. Pressure records are usually converted to the sea surface elevation in the frequency domain utilizing the transfer function derived from linear theory. The use of linear theory to convert the pressure records to the wave surface works well as long as the waves are not steep which is in accordance with the assumptions of linear theory.

The use of pressure sensors to infer surface elevation would be highly desirable as a means of conveniently measuring breaking waves, particularly high energy waves. Unfortunately, field measurements of the calculated variance of the surface elevation for breaking waves using linear theory to convert the pressure record are as much as 40 percent lower than the directly measured surface variance (Thornton, et. al., 1976). Van Dorn (1977) found comparable errors in laboratory comparison of pressure sensors and surface piercing staffs. He found that the wave troughs were properly inferred; but the wave crests were as much as 50 percent too low, which is caused primarily by a pressure reduction due to the increased velocities under the crests in the breaking wave. The resulting pressure records are much smoother and rounded off at the crests when compared with the capacitance wave gauge measurements.

Another increasingly popular and indirect means for measuring the wave surface is to use buoys with accelerometers inside them to sense changes in the sea surface elevation. The advantage of this technique is that measurements can be made in deeper water. The limitation on the depth of water in which buoys can be located is determined by the complexity or expense of the mooring systems to which they are attached. The acceleration records are integrated to obtain the displacement of the surface. The buoy has its run-up in the form of a bow wake on the face of the wave staff as the wave passes. The run-up on the staff increases with increasing diameter and flow velocity. The run-up is partially compensated by a draw down at the back side of the staff. The measurement errors associated with wave staffs needs to be determined. Also in the measure of plunging breakers, there is a question as to exactly what is measured because of multiple surfaces in the vertical in the plunge portion of wave. The influence of foam on the wave measurements is also unknown for all the wave sensors.

Other direct measurements include acoustical devices such as inverted fathometers and optical sensors using a narrow beam of light such as a laser; both of these techniques are based on measuring the time for a pulse to travel from the sensor, be reflected off the surface, and return. Acoustical and optical methods have the advantage that they do not disturb the surface. The disadvantage of the inverted fathometer is that the speed of sound is a function of temperature which can vary temporally and spatially over the vertical. The inverted fathometer also does not work in the highly turbulent region near the surf zone due to the scattering of the sound by the turbulence. The inverted fathometer does offer the advantage that it can be mounted on the bottom which is generally a much easier type of mounting as compared with the mounting of a laser beam which has to be mounted from a structure looking down on the surface.

Indirect measures of the wave surface generally have the advantage of ease in installation and are less vulnerable to the environment. For this reason, the pressure sensor is probably the most popular means of measuring the waves. The pressure sensor is usually mounted on a tripod or directly on the bottom. The water column above the pressure sensor acts as a hydraulic filter, filtering out the high frequency contributions to the wave spectrum.

antenna size, coherent scattering is generally off capillaries type waves. Bragg scatter from much longer wave lengths corresponding up to approximately 7 sec period waves has been accomplished using an over-the-horizon synthetic apperture radar reflecting off the ionesphere. The synthetic apperture radar was accomplished by driving a truck with an antenna up and down the coast. The advantage of coherent images of the surfaces is that the direction of the waves can be determined. Disadvantages of over-the-horizon radar are because the ionesphere weather does not always allow transmission and because present radars have not been able to directly measure swell-band frequencies. Radars looking at the sea surface incoherently measure the variance over a large area on the order of kilometers; it is planned to obtain this type of information routinely from SEASAT-A in the near future.

Another application is the use of a standard ship type radar based on shore looking out to sea to measure the incoming sea and swell. Again, the success of this type of measurement depends upon the presence of capillary waves to scatter the radar beam. Presently research is being pursued to determine if wave direction can be routinely measured in this manner.

REFERENCES

Thornton, E. B. and D. P. Richardson, F. L. Bub and J. J. Galvin, "Kinematics of Breaking Waves in the Surf Zone", Proceedings of the 15th Conference on Coastal Engineering, ASCE, 1976. pp 461-476.

Van Dorn, W. G., "Set-up and Run-up in Shoaling Waves", Proc. Fifteenth Coastal Engineering Conf. on Coastal Engineering, ASCE, 1976. pp 738-743.

SEDIMENT TRANSPORT MEASUREMENT IN THE NEARSHORE ENVIRONMENT:

A REVIEW OF THE STATE OF THE ART

JOHN P. DOWNING, JR
DEPARTMENT OF OCEANOGRAPHY
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

PRESENTATION MADE BY
RICHARD W. STERNBERG
DEPARTMENT OF OCEANOGRAPHY
UNIVERSITY OF WASHINGTON

INTRODUCTION

The quantitative measurement of granular material transported in the nearshore environment remains a challenging problem for oceanographers, geologists, and coastal engineers. The difficulties inherent in such measurements are attributed to: the complexities of sampling a polydisperse system (consisting of - water, clastic grains, biogenic material, and air bubbles) the stochastic nature of the transport processes, and the physical constraints on instrumentation deployed in a highly - energetic wave environment.

The primary purpose of early field measurements of nearshore sediment movement was to characterize the time averaged transport conditions to facilitate intelligent shoreline management and coastal planning. However, recent efforts to construct accurate analytical and computer models of coastal processes now require the acquisition of detailed data to resolve the spatial and temporal variability of nearshore sediment transport. Although the methodology now exists for processing a data set of this complexity (Kennedy and Lochner, 1972) there is a significant disparity between the sediment measurement and data processing technologies. This report briefly reviews the current "state of the art" of nearshore sediment transport measurement techniques. In addition to inventorying the current methodologies, some new developments are also presented that may close the technological gap described above. Our review concentrates most specifically on the available recent literature pertaining to the nearshore environment between the shoreline and the breaker line.

In reviewing this literature, it was apparent that there is no general agreement among nearshore investigators on the vertical extent of the bedload layer. This is a rather important length scale (Yalin, 1972, P. 16) and its inconsistent definition results in considerable ambiguity as to the applicability and compatability of data obtained by the large variety of measurement techniques employed in nearshore research. For the purposes of this article, we suggest that the bedload layer extends only about 10 grain diameters above the bed of stationary material; grains move as bedload in this layer (Smith and Hopkins, 1972). Above the 10 grain diameter level, the grains are transported as suspended load. The total load is thus the vector sum of the transport in these two modes. Accordingly, measurement techniques are categorized by the above criterion under one of the following major headings: bedload measurement, suspended load measurement, and total load measurement. Our category criteria can not be applied unequivocally to all studies and placement of some,tracer studies for example, under one heading or another is somewhat arbitrary.

In the fourth section of this article are reported some new developments that show promise for future research. A bibliography that lists unreferenced material also is included as an appendix that may be of interest to the reader.

BEDLOAD MEASUREMENTS

Three approaches are taken to measure the rate of grain movement across a section of the bed; these are: 1) bedload traps 2) tracer studies and 3) bedform migration studies. In nearshore applications, these methods generally do not measure bedload exclusively. Sand movement under waves appears to occur primarily in the bedload mode i.e., rolling, sliding or saltating (Ingle, 1966; Inman et al., 1969 and Komar, in press). However, in the presence of ripples and other secondary bed roughness, the moving grains are suspended for short periods of time by vortex motion near bed forms. The downward exchange of these suspended grains near the bed is measured in addition to the grains moving in contact with the bed in all of the above methods.

Bedload Traps: Bedload traps have been used extensively in flumes and wave tanks and less frequently in the field. These simple devices consist of a receptacle with an opening or grating configured so that moving grains in the vicinity of the device decelerate and fall into a collector. In flume studies, Inman and Bowen (1963) for example, the traps are placed up and down-drift of the tests bed and, following an experimental run, the accumulated material is removed from the collector, dried and weighed. In the field, bedload traps are planted by divers. The bed is allowed to re-equilibrate with the ambient flow conditions before initiating of sampling. Cook and Gorsline (1972) obtained transport data in this manner using slotted tin cans deployed in the bed just seaward of the breaker line. In their study, two trap configurations were used. One type sampled all grains moving over the slot while the second type was equipped with a hinged baffle actuated by wave surge so that grains moving onshore and offshore were selectively trapped in separate compartments. The typical sampling times ranged from 1 to 4 hours. Since Inman and Bowen (1963) and Inman and Tunstall (1972) have shown that sand movement over a rippled bed is often out of phase with the wave surge above the bed, it appears that the baffle trap probably does not, quantitatively seperate sand grains moving onshore from those moving offshore.

Brunn (1968) and Thornton (1968, 1969, 1973) employed a more sophisticated trap designed to intercept sediment moving in a layer extending 20 cm above the bed. The trap consisted of an eliptical shaped sheet metal receptacle, with pneumatically operated doors, attached to a flat metal base. The trap was used in the surf zone and was operated from a pier. After 15 - 20 minutes of sampling with the doors open, the trap was closed and flushing water was circulated through the receptacle from the pier. Trapped sand was then screened from the flushing water and weighed. The efficiency of the trap was reported to range from 40 to 100 % and apparently it varied with the wave conditions. Moreover, judging from the large size of the trap and the associated plumbing, it appears that flow distortion is very likely in the vicinity of this device.

A bedload trap similar in function to the one used by Thornton and Brunn, but configured for use by a swimmer, was designed by W. Hoyt of the University of Delaware. The trap and doors are constructed of plexiglass and closure is accomplished with surgical tubing. Field tests are currently being conducted with this device (John Kraft, personal communication).

Tracer Studies: There is some disaggreement in the recent literature regarding the exact proportion of the total littoral drift that is measured with tracers. Since it is generally assumed that the grains move in a mobile layer with some average velocity, we include the tracer studies under this section. Most of these studies, conducted with natural bed material, require the same basic assumptions. These are as follows: 1) the labeled grains have dynamic characteristics nearly identical to those of the bed material in the study area

2) transport of natural and labeled sediment occurs in a mobile layer of constant thickness

3) the areal distribution of labeled grains on the bed surface or a few centimeters below it is identical to the tracer distribution in the entire volume of the mobile layer

4) most of the tracer (80%, Komar and Inman, 1970) remains in the surveyed portion of the study area.

Although a variety of labeling materials were used successfully in early tracer work, radioisotopic and fluorescent materials are used almost exclusively at the present time. Teleki (1963, 1966, 1967) discusses the technology of applying optically-active dyes to sand grains and the methods of grain counting. The practical and theoretical considerations pertaining to fluorescent labeled sands used in the surf zone are examined in detail by Ingle (1966) and Ingle and Gorsline (1973). Similarly, the labeling of natural and artificial sediment particles with radioactive substances, their handling and application in near-shore research is developed in a number of papers (see for example Circkmore and Lean (1962) and Smith (1973). Because individual labeling techniques are governed by the equipment and resources available to the individual investigator, a detailed summary of methodology will not be given here.

Two methods of determining transport rates from tracer distribution data are in use (Courtois and Monaco, 1969). These are the space integration

(Lagrangian) method and the time integration (Eulerian) method, also called the dilution method (Russell, 1961). In the former method, labeled sediment is instantaneously injected at a point or on a line and allowed to disperse for some time. The centroid of the tracer distribution then is determined by a synoptic survey of the study area. The displacement of the centroid from the injection point during the elapsed time of the study is used to estimate the average speed of grain motion within the mobile layer. The thickness of the mobile layer is estimated from tracer stratigraphy in sediment cores or by the erosion depth of tracer buried in the foreshore (Williams, 1971). A simple equation can be applied to obtain the bulk volume transport rate. Komar and Inman (1970), for instance, use an equation of the form:

$$S = bX_b(V_\ell)$$

Where: S = bulk volume longshore transport rate, b = thickness of the mobile layer, x_b = width of the beach, and V_ℓ = average speed of grain motion.

In the time integration method, the labeled sediment can be injected either quasi - continuously,at a constant rate,or instantaneously. Following the injection, the concentration of the tracer is measured periodically along transects orthogonal to the presumed direction of littoral drift for the duration of the experiment. Computation of the transport rate is made with an equation similar to Kadibs (1973) which is given below:

$$Q = \frac{S_X}{\int_o^L \int_o^T C\,dy\,dt}$$

Where: Q = mass transport of sediment per unit time per unit width of beach, S_X = total amount of tracer passing a transect in time T (the elapsed time between the first arrival and the disappearance of tracer grains from the transect) L = length of the transect, and C = the tracer concentration at a sampling point. The values of Q calculated from this equation are average transport conditions for the duration of the experiment. In Kadib's study, the integrals were evaluated graphically.

Of the recent work with fluorescent tracers, the studies by Inman et al. (1969), Komar and Inman (1970), and Kadib (1973) have produced the most quantitative transport rate results. As previously mentioned, the Inman - Komar studies used the space integration method. The labeled sand was injected along a line, on the beach face, perpendicular to the shoreline. After an appropriate time (2-4 hours), the tracer distribution was determined by collecting volume samples of the beach face to a depth of 5 cm. The sensitivity of the counting technique was reported to be 1 labeled grain per 10^7 - 10^8 unlabeled grains. From the contoured tracer distribution map, the centroid was determined by taking the first moment of the tracer concentration about the injection line in the longshore direction.

In Kadib's study, labeled sand was injected at a point 20 m seaward of the shoreline at the rate of 50 kg/ 2 days. The duration of the injection was 21 days and the tracer concentration field was ascertained by volume sampling (upper 2 cm of the bed) along transects perpendicular to the shoreline once every 2 days. The sampling lines extended offshore to the point where the labeled grains were undetectable. No minimum detection limits for tracer grains were reported by Kadib. Although a mobile layer thickness need not be assumed in the time integration method, Kadib assumed that the net littoral drift was unidirectional for the duration of the experiment and that moving grains crossed the transects only once.

There are two major advantages associated with radioactive labeling of tracer materials. Unlike fluorescent tagged sand, radioactive sand is rapidly detectable in situ. Submersible detectors are capable of surveying a large study area almost synoptically whereas volume sampling for a fluorescent tracer on a moderate sized grid ($\tilde{}3000$ m^2) takes at least one hour. Moreover, a significantly larger proportion of the dispersal area is sampled. In the

Radioisotopic Sand Tracer (RIST) project typical survey coverage with the towed detector is about 2.4% of the dispersal area (~160,000 m^2) compared to the 0.0021% coverage obtained by Ingle (1966) with his greased cards (Judge, 1975).

Of the recent work with radioisotopic tracers, the most quantitative results were obtained by Courtois and Monaco (1969). The tracer grains were labeled with Cr^{51}, a 0.325 mev gamma emitter, and in situ detection was accomplished with two scintillation detectors mounted on a towed sledge. Transport rates were computed by the space integration method and the thickness of the mobile layer was determined by the count rate balance operation (Courtois and Sauzay, 1966). In this latter operation, the depth of tracer burial is related to: the difference between the integrated count rate measured at the time of injection and at the time of the survey, and the characteristics of the gamma detectors.

Since 1966, the RIST system has been used by the Coastal Engineering Research Center at a number of sites on the east and west coasts of the United States. Sand indigenous to the study area is labeled with one of three isotopes-$Au^{198/199}$ and Xe^{123}; $Au^{198/199}$ emit gamma radiation in the 0.2 - 0.4 mev range. A unique detector system is used for surveying the study area. It consisted of four scintillation detectors mounted in a cylindrical shaped protective cage that rolls on the sea bed and is capable of negotiating a variety of bottom types from sand to cobbles. The detector system examines a 2 ft wide area and is towed by a large amphibious vehicle (LARC - 15) that can operate in 6 - 8 ft surf at towing speeds up to 6 kts. At the maximum towing speed, a area of 113 m^2 min^{-1} is swept by the detector. The data acquisition system is highly automated. On board, paper tape recorders sample time, vehicle position data, and gamma counts every 2 sec. Shore based computers programed with RAPLOT (Brashear et al, 1970; Turner, 1970) reduce the positioning data to X - Y coordinates, correct the gamma count data for decay since injection and background radiation, and produce a graphic plot of the tracer distribution. The cost of a field experiment ranges from \$10,000 -\$60,000 depending on the degree of sight preparation required (Judge, 1975).

The use of the RIST system to date in the nearshore environment has been limited to investigations of sand dispersal patterns. Few, if any, transport rate data have been obtained during the many field deployments of the system. The results of the project therefore, must be considered qualitative. Although tracer movement can be monitored very rapidly and precisely, the determination of transport rates from the tracer distribution is subject to the same uncertainties that limit the less sophisticated tracer survey methods. Before transport rates can be determined from tracer studies with greater confidence, the problems of variable dispersion (Price, 1968), differential lateral transport (Duane, 1970), and spatial variation in the mobile layer thickness will have to be clarified.

<u>Bedform Migration</u>: Kachel and Sternberg (1971) measured bedload transport as ripples on a shallow tidal bank (~30 m) by analyzing time lapse stereographic bottom photographs taken from a tripod placed on the bottom. Agreement of transport rates obtained from ripple migration data with the rates determined from simultaneous estimates of shear velocity (U_*) suggest that similar methods might be applied in the nearshore zone. High resolution ultrasonic profilers capable of rapid and accurate mapping of bedforms are available (Dingler et al., In Press) but a number of these devices would have to be used simultaneously to monitor bedform migration in low visibility conditions.

Although it is feasible to obtain the necessary data to determine bedload transport rates by the Kachel - Sternberg method, recent studies of ripple formation under waves suggest that ripple movement may not be a reliable indicator of the rate of grain motion. The ripple regime is bounded by the flow conditions that initiate grain motion and the onset of sheet flow (Dingler and Inman, in press). Sheet flow commences at a wave form Shields criterion θ value of about 40, where: $\theta = \rho U_m^2 / \gamma_s D$, ρ = fluid density, U_m = maximum near-bottom orbital velocity, $\gamma_s = (\rho_s - \rho)g$, ρ_s = grain density, and D = grain size. The transition to sheet flow is complete and ripples disappear entirely from the bed at $\theta_c = 240$. In the transition region ($40 < \theta < 240$) both ripples and sheet flow can coexist.

Field evidence indicates that ripples under shoaling gravity waves migrate in the direction of wave propagation ie. onshore (Dingler and Inman, in press). Laboratory flume experiments, however, suggest that ripples under waves superimposed on a current flowing in the direction of wave propagation can migrate in the direction opposite to wave propagation (Inman and Bowen, 1963). It is apparent that the process of sediment transport near a rippled bed under the influence of both oscillatory and steady flows is not totally understood. For this reason and because ripples and sheet flow can coexist under a wide range of flow conditions, bed topography time series data can not be considered reliable for the prediction of bedload transport rates.

SUSPENDED LOAD MEASUREMENTS

Suspended solids can be measured directly with the use of mechanical sampling devices or indirectly with sensing intrumentation based on a variety of physical principles.

Mechanical Devices: Mechanical samplers currently used in the nearshore environment are of the point integrating and instantaneous types. Both types take a bulk volume sample; the latter does so rapidly (< a few seconds) while the former samples at a fixed point over an extended time period (> 10's seconds). Suspensates in the surf zone have a wide range of dynamic characteristics. Clay, silt and diatoms, for example, are in the Stokes' range ($R_e <$ about 3.5) whereas the flow around settling sand grains has Reynolds numbers greater than 3.5. Much uncertainty exists therefore regarding sampler efficiency. This is particularly true for particles outside the Stokes' range. This uncertainty is greatest for devices that draw a volume sample through a small orifice because accelerations of the suspension may be large in the region near the orifice.

Kana (1976) designed an instantaneous sampler for use in the surf zone. The device consists of a portable vertical array of four small Van Dorn type bottles (Vol. ~2000 ml.) that is operated by a swimmer. The apparatus can be rigged for use in about 30 seconds and good results have been obtained during 40 days of field tests. The Shore Processes Laboratory (SIO) is developing a device with similar capabilities. The SPL sampler consists of a clear-plastic cylinder internally divided by pistons. Large ports in the cylinder allow the sample volume to enter the chambers between the pistons; upon actuation, the cylinder slides downward trapping the samples in the chambers. Both the Kana and SPL samplers have large ratios of entry port area to chamber volume and therefore the flow probably does not accelerate appreciably while entering the openings. However, the testing to date has not established the flushing characteristics of the chambers prior to activation nor has the flow field in the vicinity of the devices been investigated in any detail. Because these samplers are swimmer operated, the exact position of the samples in the water column is generally not known. Although the samplers are fairly compact, they disturb the flow to some degree and can not be used in close proximity to current meters.

A sampler that takes a core of the otherwise undisturbed suspension by thrusting a rigid cylinder around the sample volume has been used in the surf and swash zones on the University of Washington field trips. The support frame and closure mechanism, in their present form, are prohibitively large and thus the sampler can not be used close to current meters for the reason given above. A compact, remotely actuated, version of this device is being built by the Sediment Dynamics Group (U of W) for use on a surf zone instrumentation system.

The preponderance of surf zone suspended sediment data has been acquired with point integrating samplers. See, for examples, studies by: Watts (1953), Fairchild (1956, 1959, 1971, 1973), Cook and Gorsline (1972), Jensen and Sorensen (1972), Fukushima et al. (1964), and Basinski and Lewandowski (1975). Both pumping systems and stationary traps with openings for sediment [illegible] into (bamboo samplers and Cook and Gorslines vials) are of this type.

Laboratory and flume studies conducted at St. Anthony Falls Hydraulic Laboratory (Reports No. 6 & 13, 1952 & 1961) established that the efficiencey of samplers that draw a volume of suspension through a nozzle is greatly affected by the angle between the nozzle axis and the mean flow direction and the ratio of the intake speed at the nozzle orifice and the mean flow speed. In the case of pump sample used in turbulent oscillatory flow, it is physically impossible to keep the intake nozzle axis parallel with the mean flow direction and simultaneously vary the intake flow speed in phase with the wave surge. Although pumps are usually operated continuously over several wave periods, it is not certain that sampling errors of the above type will cancel in the averaging process. Further uncertainty results when the samples are pumped tens of feet through hoses or tubes. It is not anticipated that future developments in pump sampling technology will alleviate all of these problems.

Bamboo samplers and vial traps appear to be a useful means of obtaining time-averaged vertical profiles of relative suspended sediment concentration. Since the efficiency of these devices has not been accurately determined at various levels of turbulence intensity, it is not clear what percentage of the suspended load is actuall measured nor is a reference concentration at any sampling level accurately known. Furthermore, the effect of flow disturbances near the device on its grain trapping characteristics has not been evaluated. These limitations and the destructive nature of the surf and breaker zones prohibit the use of currently available trap designs in moderate to heavy surf conditions.

Indirect Sensing Instruments: Photo-electric transmissometers (Homma and Horikawa, 1963 and Homma et al., 1965) and, to a lesser degree, electrical-resistance particle counters (Hattori, 1969) have been used in many flume studies of sediment suspension under waves. Brenninkmeyer (1975, 1976) has published the only recent field results obtained with a photo-electric device used inside the breaker zone.

Brenninkmeyer's almometer consists of a high intensity fluorescent lamp mounted vertically and parallel to an adjacent array of 64 photo cells. The working concentration range of the instrument is 10 -500 g l^{-1} and the sampling rate is 5 Hz. Experiments to date have been conducted in the swash zone. Since the lower limit of the concentration detection range is about 4 times the maximum concentration (2.5 ppt) obtained with pump samplers (Fairchild, 1971, 1973), the almometer is of limited use in the surf and breaker zones with its present sensitivity.

An integrated light scatterance/transmissometer instrument has been developed at the Shore Processes Laboratory (SIO). The device has been calibrated in a turbidity tank and deployed in the field for preliminary testing. Because of its rugged construction and very compact geometry, the instrument produces minimal distortion of the velocity field.

The major deficiency of both scatterance and transmission type electro-optical instruments is their inability to distinguish among the many types of suspended particles encountered in the nearshore waters. Clastic grains, air bubbles, plankton and organic debris all scatter and absorb light to some degree. Future research with this class of instrumentation will have to overcome this difficulty before quantitative results can be acquired.

Measurements of X-ray and gamma radiation absorption in suspensions have been used to determine particle concentrations and distribution in nearshore waters (Murhree et al., 1968 and Basinski and Lewandowski, 1975). The attenuation of radiation passing through a material can be expressed as:

$$I = I_o \, e^{-\rho\mu\ell}$$

Where: I_o and I are the initial intensity and the intensity at a distance ℓ respectively, ρ is the bulk density and μ is the mass absorption coeffecient. It can be seen from this equation that absorption is affected oppositely by low density materials such as bubbles and high density clastic grains. Consequently, sensor output levels do not correspond to unique suspended sand concentrations. Furthermore the mass absorption coefficient is dependent on the chemical compositions of both the suspensate and the seawater and therefore recalibration of a source-detector system is required for each study area. The instruments used in the above studies are large and require rather cumbersome mounting platforms (ie. pilings and towers). The potential for local scour of the sea bed around such structures is large and the flow distortions they produce prohibit the use of current meters nearby.

TOTAL LOAD MEASUREMENTS

Total littoral drift rates have been determined from temporal sand volume changes at littoral barriers in several studies (Watts, 1953; Caldwell, 1956 and Moore and Cole, 1960). Sand volume changes in these studies were determined by periodic topographic and bathymetric surveys except in the Watts study in which the pumping rate of a sand bypassing plant was monitored. In a recent study by Bruno and Gable (in press) sophisticated electronic ranging equipment was used for vessel positioning during the surveys but the basic methods and assumptions were essentially the same ones applied in the older works cited above.

Littoral barrier studies resolve the total transport rates to a time scale commensuate with the frequency of the surveys and thus they provide only time averaged estimates. Changes in beach topography have diurnal, fortnightly and annual periods (Inman and Filloux, 1960 and Aubrey et al., 1970); moreover they occur randomly on a storm by storm basis. Although the movement of sand coincident with periodic profile changes has a large on and off-shore component and ideally does not alter the longshore sand budget significantly, these changes contribute to the uncertainty of the sand volume estimates in a manner analogous to aliasing. Estimates of these errors should be included as confidence limits about the calculated transport rates, however, this is done rarely. In our opinion, further efforts to relate time averaged transport rates obtained from littoral barriers to time averaged wave parameters will not lead to much additional insight into the physics of the littoral transport process.

NEW DEVELOPMENTS

<u>Acoustic Devices</u>: A variety of instrument systems operating in the ultrasonic frequency range are currently used by the medical profession for: monitoring of blood flow rates, particle and gas bubble detection, and tissue scanning. Medical ultrasonic devices function in several modes: doppler shift, surface scatterance, volume scatterance, and cavity resonance. All four modes are potentially applicable to the sediment measurement problem.

Ultrasonic scanner systems similar to the ones used for bedform profiling (Dingler et al., in press) might be used in the volume scatterance mode to detect particles suspended near the bed. When combined with a probe, operating in the doppler shift mode, a composite system for measuring the number and speed of particles moving in sheet flow might be feasible. A system of this type is being developed by Wenzel (1974) for the measurement of suspended sediment transport. His system combines a doppler shift current meter and a volume scatterance meter with an acoustic path length of 60 cm. D. Rhoades of Yale University has done preliminary evaluations of medical scanners in the 2.5 - 5.0 mHz frequency range for profiling the upper 10 cm of the sediment column. Rhoades reports that suspended material above the bed is clearly detectable and that 1 mm resolution is attainable with medical scanners. A bottom concentration velocity (BCV) probe developed for the INSTEP Project (Inner Shelf Sediment Transport Experiment; D. Swift, Coordinator) is now being field tested on the continental shelf. This system consist of a vertical array of electromagnetic current meters and an acoustic scatterance device. The latter component is a downward looking 3 mHz transducer with a path length of 100 cm and a beam width of about 1 cm. The backscatter is gated at 0.5 cm intervals to resolve the vertical distribution of suspended particles in the beam path.

These acoustic scatterance instruments appear to have great potential for gathering time series sediment transport data in bubble-free environments. However, at the present time, signal processing technology does not include a means for removing the bubble contributions to the scatterance signal. Their use in the surf zone will remain limited until the bubble problem is solved.

Heyman et al. (1975) reported the development of an ultrasonic resonator that is capable of counting small particles in a through flowing liquid. At its present stage of development, the system produces relative errors of about 10% at a count rate of 4.3 sec^{-1} and it has a maximum counting rate well below that necessary for operation in the surf zone. However, appropriate modifications to the detector could make it useful for measuring low suspended sand concentrations in nearshore waters. An integrated system might be developed by combining an acoustic particle counter that functions well at low concentration levels with a sensor that is reliable at high concentrations.

Passive (non-transmitting) listening devices have the capability to discriminate between moving clastic material and low density suspensates. Anderson (1976) successfully detected the time varying bedload movement in a small stream with a sensitive piezoelectric microphone and his preliminary tests suggest a similar system may be applicable in the surf zone. D. Wilson at the Westinghouse Ocean Research Laboratory has developed a passive acoustic device for detecting suspended particles. It consists of a piezoelectric wafer coupled to an aluminum detector rod. The collisions of entrained sand grains (> 0.1 mm) against the detector rod as the suspension flows around it can be counted electronically with the device.

Passive detectors have great potential for accurately measuring sediment transport in the surf zone. They are small in size, geometrically simple,and since grain collisions result from inertial characteristics these sensors can be designed to respond to clastic particles rather than air bubbles or particles in the Stokes' range.

OTHER PRINCIPLES:

A laser scatterance instrument developed by E. Thornton and W. Morris (Naval Postgraduate School, Monterey) was recently field tested in the surf near San Diego. The instrument consists of a submersible forward-scattering laser nephelometer through which suspension is pumped from intakes mounted at various levels above the sea bed. Calibration is accomplished by pumping the suspension through a PVC pipe to the shore and determining particle concentrations directly by gravimetric techniques. In the initial tests, particle concentrations measured by the scatterance meter agreed rather well with those measured in direct instantaneous (Thornton, personal communication) samples taken near the intake nozzles.

A new type of measurement principal is under consideration by the sediment Dynamics Group (U of W). A solid slab of material forced to vibrate in a fluid has entrained around it a fluid boundary layer that is a part of the oscillating system. The presence of particles of specific gravities different than the ambient fluid alter the inertial characteristics of this oscillator system and produce a variation in the operating frequency. Since air bubbles and clastic grains produce a frequency shift of different sign, it should be possible to remove the bubble contribution by operating two oscillators simultaneously at different frequencies and processing their signals appropriately.

Although the air bubble problem may be surmounted with vibrating reed sensor elements, temperature drift and directional response may present additional problems during their calibration and field use. Moreover, since the sensor effectively samples only the volume of the boundary layer, it is not clear that the measurements will be statistically significant at low concentrations or for the rapid sampling rates necessary in the surf zone. These problems must be carefully evaluated before construction of a prototype unit is initiated.

CONCLUSION

With the advent of reliable electromagnetic current meters, pressure transducers, and wave recording staffs, the accurate measurement of the wave and current regimes that comprise the nearshore sediment transport forcing function is now a realistic goal. It is apparent, however, that the instrumentation necessary to make measurements of the transport response function to equivalent detail does not exist at the present time. Until this technological gap is closed, substantial progress in relating the forcing and response functions of the nearshore sediment transport process will not be possible.

REFERENCES

Anderson, M. G., 1976, An inexpensive circuit design for the acoustic detection of oscillations in bedload transport in natural streams. Earth Surface Processes, v. 1, p. 213-217.

Aubrey, D. G., D. L. Inman, and C. E. Nordstrom, 1976, Beach profiles at Torrey Pines, California. Proc. 15th Conf. Coastal Eng., Am. Soc. Civ. Eng.,

Basinski, T., and A. Lewandowski, 1975, Field investigations of suspended sediment. Proc. 14th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1096-1101.

Brashear, H. R., E. H. Acree, F. N. Case, P. A. Turner, and D. B. Duane, 1970, Processing and analysis of radioisotopic sand tracer (Rist) study data. Proc. 12th Conf., Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 821-830.

Brenninkmeyer, B. M., 1974, Mode and period of sand transport in the surf zone. Proc. 14th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 812-827.

Brenninkmeyer, B. M., 1976, In-situ measurements of rapidly fluctuating high sediment concentrations. Mar. Geol., v. 20(2),pp. 117-128.

Bruno, R. O., and C. G. Gable, preprint, Longshore transport at a littoral barrier.

Bruun, P., 1968, Quantitative tracing of littoral drift. Proc. 11th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. I, pp. 322-328.

Caldwell, J. M., 1956, Wave action and sand movement near Anaheim Bay, California. Beach Erosion Board, Tech. Memo. No. 68, 21 p.

Cook, D. O., and D. S. Gorsline, 1972, Field observations of sand transport by shoaling waves. Mar. Geol., v. 13(1), pp. 31-55.

Courtois, G., and Sauzay, G., 1966, Count rate balance methods using radioactive tracers for measuring sediment wave flows. Houille Blanche, v. 3, pp. 279-290.

Courtois, G., and A. Monaco, 1969, Radioactive methods for the quantitative determination of coastal drift rate. Mar. Geol., v. 7(3), pp. 183-206.

Crickmore, M., and E. H. Lean, 1962, The measurement of sand transport by means of radioactive tracers. Proc. Roy. Soc. (London), Ser. A., 266(1326), pp. 402-421.

Dingler, J. R., J. C. Boylls, and B. L. Lowe, preprint, A high frequency sonar for profiling small-scale subaqueous bedforms.

Duane, D. B., 1970, Tracing sand movement in the littoral zone: Progress in the radioisotope sand tracer (RIST) study. Coastal Eng. Res. Cen. Misc. Paper No. 4-70, 46p.

Fairchild, J. C., 1956, Development of suspended sediment samplers for laboratory use under wave action. Beach Erosion Board Bull., vol. 10(1), pp. 41-59.

Fairchild, J. C., 1959, Suspended sediment sampling in laboratory wave action. Beach Erosion Board Tech. Memo. No. 115, 25p.

Fairchild, J. C., 1971, Suspended sediment concentration in the surf zone. Trans. A.G.U., v. 52(4), p. 260.

Fairchild, J. C., 1973, Longshore transport of suspended sediment. Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1069-1088.

Fukushima, H., M. Kashiwamura, I. Yakuwa, and S. Takahashi, 1964, A study on the sand drift along the coast of Hidaka in Hokkaido. Coastal Engineering in Japan, v. 7, pp. 109-124.

Hattori, M., 1969, The mechanics of suspended sediment due to standing waves. Coastal Engineering in Japan, v. 12, pp. 69-81.

Heyman, J. S., D. Dietz, and J. G. Miller, 1975, A non-doppler ultrasonic monitor for particulates in flowing liquids. Proc. IEEE. Ultrasonic symp., 75 CHO 994-4SU, pp. 561-565.

Hom-ma, U and K. Horikawa, 1962, Suspended sediment due to wave action. Proc. 8th Conf. Coastal Eng., Am. Soc. Civ. Eng., , pp. 168-193.

Hom-ma, U, K. Horikawa, and R. Kajima, 1965, A study on suspended sediment due to wave action. Coastal Engineering in Japan, v. 8, pp. 85-103.

Ingle, Jr., J. C., 1966, The movement of beach sand. Elsevier Publ. Co., Amsterdam, 221p.

Ingle, Jr., J. C., and D. S. Gorsline, 1973, Use of fluorescent tracers in the nearshore environment. In: Tracer Techniques in Sediment Transport, Int. At. Energy Agency, Vienna, pp. 125-148.

Inman, D. L., and J. Filloux, 1960. Beach cycles related to tide and local wind wave regime. Jour. Geol., v. 63(2), p. 225-231.

Inman, D. L., and A. J. Bowen, 1962, Flume experiments on sand transport by waves and currents. Proc. 8th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 137-150.

Inman, D. L., P. D. Komar, and A. J. Bowen, 1968, Longshore transport of sand. Proc. 11th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. I, pp. 298-306.

Inman, D. L., and E. B. Tunstall, 1972, Phase dependent roughness control of sand movement. Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1155-1172.

Jensen, J. K., and T. Sorensen, 1972, Measurements of sediment suspension in combinations of waves and currents. Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1097-1104.

Judge, C. W., 1975, Use of Radioisotopic sand tracer (RIST) system. Costal Eng. Res. Cen. Tech. Memo. No. 53, 75p.

Kadib, Abdel-Latif, A., 1973, Rate of sediment motion using fluorescent tracer. Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 985-1004.

Kana, T. W., 1976, A new apparatus for collecting simultaneous water samples in the surf zone. Jour. Sed. Pet., v. 46(4), pp. 1031-1034.

Kennedy, J. F., and Locher, F. A., 1972, Sediment suspension by water waves. In: Meyer, R. E., ed., Waves on Beaches and Resulting Sediment Transport, Academic Press, London, pp. 249-296.

Komar, P. D., and D. L. Inman, 1970, Longshore sand transport on beaches. J. Geophys. Res., v. 75(30), pp. 5914-5927.

Komar, P. D., preprint, Selective longshore transport rates of different grain-size fractions within a beach.

Moore, G. W., and Cole, J. M., 1960, Coastal processes in the vicinity of Cape Thompson, Alaska, U. S. G. S. Trace elements investigation rep. no. 753.

Murhree, C. E., et al., 1968, Field test on x-ray sediment-concentration gage. Proc. Am. Soc. Civ. Eng., v. 94, no. HY2.

Price, W. A., 1968, Variable dispersion and its effects on the movements of tracers on beaches. Proc. 11th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. I, pp. 329-334.

Russell, R. C. H., 1960, The use of fluorescent tracers for the measurement of littoral drift. Proc. 7th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. I, pp. 418-444.

Smith, D. B., 1973, The use of artificial radioactive tracers in the United Kingdom. In: Tracer techniques in sediment transport, Int. At. Energy Agency, Vienna, pp. 97-102.

Smith, J. D., and T. S. Hopkins, 1972, Sediment transport on the continental shelf off of Washington and Oregon in light of Recent current measurements. In: Shelf sediment transport: Process and Pattern, ed., Swift, D. J. P., Duane, D. B., and Pilkey, O. H., pp. 143-180.

St. Anthony Falls Hydraulic Laboratory, 1952, The design of improved types of suspended sediment samplers. Report No. 6, 103p.

St. Anthony Falls Hydraulic Laboratory, 1961, Single-stage sampler for suspended sediment. Report No. 13, 103p.

Teleki, P. G., 1963, A summary of the production and scanning of fluorescent tracers. Proc. Fed. Interagency Sedimentation Conf., U. S. Dept. of Agric., Misc. Publ. 970, 11p.

Teleki, P. G., 1966, Fluorescent sand tracers. Jour. Sed. Petrol., v. 36(2), pp. 468-485.

Teleki, P. G., 1967, Automatic analysis of tracer sand. Jour. Sed. Petrol., v. 37(3), pp. 749-759.

Thornton, E. B., 1968, A field investigation of sand transport in the surf zone. Proc. 11th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. I, pp. 335-351.

Thornton, E. B., 1969, Longshore current and sediment transport. Tech. Rept. No. 5, Dept. Coastal and Oceanog. Eng., Univ. of Florida, Gainesville.

Thornton, E. B., 1972, Distribution of sediment transport across the surf zone. Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1049-1068.

Turner, P. A., 1970, RAPLOT, a computer program for data processing and graphical display for radioisotopic sand tracer study. Coastal Eng. Res. Cen. Misc. Paper No. 3-70, 60p.

Watts, G. M., 1953, Field investigation of suspended sediment in the surf zone. Proc. 4th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 181-199.

Watts, G. M., 1953, A study of sand movement at Lake Worth Inlet, Florida. Beach Erosion Board Tech. Memo No. 42, 24 p.

Wenzel, D., 1974, Measuring sand discharge near the sea-bottom. Proc. 14th Conf. Coastal Eng., Am. Soc. Civ. Eng., V. I, pp. 37-42.

Williams, A. T., 1971, An analysis of some factors involved in the depth of disturbance of beach sand by waves. Mar. Geol., v. 11 (3), pp. 145-158.

Yalin, M. S., 1972, Mechanics of sediment transport. Pergamon Press, New York, 290p.

APPENDIX: BIBLIOGRAPHY

Acree, E. H., H. R. Brashear, and F. N. Case, 1970, Underwater survey system for radionuclide-tagged sediment tracing. Proc. 12th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 815-820.

Arlman, J. J., Santema, P. and Svasek, J. N., 1958, Movement of bottom sediment in coastal waters by currents and waves: measurements with the aid of radioactive tracers in The Netherlands. U. S. Army Beach Erosion Board Tech. Memo 105: 56p.

Bhattacharya, P. K., 1971, Sediment suspension in shoaling waves. PhD Thesis, Univ. of Iowa.

Brattleland, E., and P. Bruun, 1974, Tracer tests in the middle North Sea. Proc. 14th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 978-990.

Bruun, P., 1962, Tracing of material movement on seashores. Shore and Beach, 30, pp. 10-15.

Bruun, P., and Purpura, J. A., 1964, Quantitative research on littoral drift in field and laboratory. Proc. 9th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 267-288.

Crickmore, M., and G. H. Lean, 1962, The measurement of sand transport by the time integration method with radioactive tracers. Proc. Roy. Soc. (London), Ser. A., 270 (1340), pp. 27-47.

Das, M. M., 1971, Mechanics of sediment suspension due to oscillatory water waves. Rep. HEL-2-32, Univ. California, Berkeley.

Das, M. M., 1971, Longshore sediment transport rates: a compilation of data. Coastal Eng. Res. Cen. Misc. Paper, no. 1-71, 75p.

Das, M. M., 1972, Suspended sediment and longshore sediment transport data review. Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1027-1048.

De Vries, M., 1973, Applicability of fluorescent tracers, In: Tracer techniques in sediment transport, Int. At. Energy Agency, Vienna, pp. 105-123.

Duane, D.B., and C. W. Judge, 1969, Radioisotopic sand tracer study Point Conception, California. Coastal Eng. Res. Cen. Misc Paper No. 2-69, 81 p.

Duane, D. B., 1970, Synoptic observations of sand movement. Proc. 12th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 799-814.

Fukushima, H., and M. Kashiwamura, 1961, Some experiments on bamboo samplers. Coastal Engineering in Japan, v. 4, pp. 61-64.

Gohren, H., and H. Laucht, 1972, Instrument for long-term measurement of suspended matter (SILTGUAGE). Proc. 13th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 1089-1096.

Hails, J. R., 1974, A review of some current trends in nearshore reserach. Earth-Sci. Rev., v. 10, pp. 171-202.

Horikawa, K., and A. Watanabe, 1970, Turbulence and sediment concentration due to waves. Proc. 12th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. II, pp. 751-766.

Hubell, D., and W. W. Sayre, 1974, Sand transport studies with radioactive tracers. J. Hydraulics Div., Am. Soc. Civil. Engrs., 90, pp. 39-69.

Inman, D. L., 1949, Sediment trap studies of suspended material near the surf zone. Scripps Inst. Oceanogr. Q., Prog. Rep. to U. S. Army Corps Eng. BEB, 2, pp. 5-6.

Inman, D. L., and T. K Chamberlain, 1959, Tracing beach sand movement with irradiated quartz. J. Geophys. Res., v. 64(1), p. 41-47.

Inose, S., H. Kato, S. Sato, and M. Shiraishi, 1955, The field experiment of littoral drift using radioactive glass sand. Proc. U.N. Intern. Conf. Peaceful Uses At. Energy, Geneva, 15(8), pp. 211-219.

Inose, S., and Shiraishi, N., 1956. The measurement of littoral drift by radioisotopes. Dock Harbour Auth., 36, pp. 284-288.

Jaffy, P., and R. Hours, 1959, Study of littoral transport by radioactive tracer methods. Cahiers Oceanogr., 11, pp. 475-498.

Joliffe,I.P..1961, The use of tracers to study beach movements and measurement of littoral drift by a fluorescent technique. Rev. Geomorphol. Dyn., v. 12(2), pp. 81-98.

Joliffe, I. P., 1964, An experiment designed to compare the relative rates of movement of different sizes of beach pebbles. Proc. Geol. Assoc. 75, pp. 67-86.

Kamel, A. M., and J. W. Johnson, 1962, Tracing coastal sediment movement by naturally radioactive minerals. Proc. 8th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 324-330.

Kidson, C., D. B. Smith, and J. A. Steers, 1956, Drift experiments with radioactive pebbles. Nature, v. 178(4257), p. 257.

Kidson, C., Carr, A. P., and D. B. Smith, 1958, Further experiments using radioactive methods to detect movement of shingle over the seabed and alongshore. Geog. J., v. 124, pp. 210-218.

Kidson, C. and A. P. Carr, 1959, The movement of shingle over the seabed close inshore. Geogr. J., v. 125, pp. 380-389.

Kidson, C., and A. P. Carr, 1961, Beach drift experiments at Bridgwater Bay, Somerset. Proc. Bristol Nat. Soc., v. 30, pp. 163-180.

Kidson, C., and A. P. Carr, 1962, Marking beach material for tracing experiments. J. Hydraul. Div. Proc. Am. Soc., Civ. Eng., v. 3189 (HY4), pp. 43-60.

Komar, P. D., 1969, The longshore transport of sand on beaches. Thesis, Univ. Calif., San Diego.

Longinov, V. V., 1968, Determination by a photo-electric method of sand suspension concentration in the littoral zone during waves. Gosudarstvennyi proektno - Konstruktorskii i Naucho - issledovatel'Skii Inst. Morskogo Transporta (Leningrad), v. 20/26, pp. 82-92.

Russell, R. C. H., 1960, Use of fluorescent tracers for the measurement of littoral drift. Proc. 7th Conf. Coastal Eng., Council Wave Res. Univ. California, Berkeley. pp. 418-444.

Medvedev, V. C., and Aibulatov, N. A., 1956, The use of "labelled" sand to study the movement of material. Izv. Akad. Nauk S.S.S.R., Ser. Geogr., v. 4, pp. 99-102.

Miller, R. L., 1972, Study of air entrainment in breaker waves. Am. Geophys. Union Trans. v. 53, p. 426.

Muir, T. C., 1968, A study in the estimation and measurement of bedload discharge. PhD thesis, Univ. of Newcastle-upon-Tyne, England.

Murray, S. P., 1967, Control of grain dispersion by particle size and wave state. J. Geol., v. 75(5), pp. 612-634.

Orlova, G. A., 1963, A study in the determination of the total amount of sand drifts displaced along the sea coast. Okeanologia, v. 3, pp. 924-929.

Phillips, A. W., 1963, Tracer experiments at Spurn Head, Yorkshire, England. Shore and Beach, v. 31, pp. 30-35.

Putnam, J. L., and D. B. Smith, 1956, Radioactive tracer technique for sand and silt movements under water. Intern. J. Appl. Radiation Isotopes, v. 1 (1), pp. 24-32.

Reid, W. J., and J. P. Jolliffe, 1961, Coastal experiments with fluorescent tracers. Dock Harbour Auth., v. 41, pp. 341-345.

Reimnitz, E., and D. A. Ross, 1971, The sea sled - a device for measuring bottom profiles in the surf zone. Mar. Geol., v. 11, pp. 1727-1732.

Russell, R. C. H., Newman, D. E., and Tomlinson, K. W., 1963, Sediment discharges measured by continuous injection of tracers from a point. Int. Assoc. Hydraul. Res., Congr., 10th, London, v. 1, pp. 69-76.

Sato, S., Ijima, T., and N. Tanaka, 1962, A study of critical depth and mode of sand movement using radioactive glass sand. Proc. 8th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 304-323.

Sauzay, G., 1973, Tracer techniques in sediment transport: Report of the panel. In: Tracer techniques in sediment transport. Int. At. Energy Agency, Vienna, pp. 3-8.

Schiemer, E.W., and J. R. Schubel, 1970, A near bottom suspended sediment sampling system for studies of resuspension. Limnol. & Oceanog., v. 15, pp. 644-646.

Shoji, S., T. Ijima and N. Tanaica, 1962, A study of critical depth and mode of sand movement using radioactive glass sand. Proc. 8th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 304-323.

Smith, D. B., 1973, The use of artificial radioactive tracers in the United Kingdom. In: Tracer techniques in sediment transport. Int. At. Energy Agency, Vienna, pp. 97-102.

Stuiver, M., and J. A. Purpura, 1969, Application of fluorescent coated sand in littoral drift and inlet studies. Proc. 11th Conf. Coastal Eng., Am. Soc. Civ. Eng., v. 1, pp. 307-321.

Svasek, J. N., and H. Engel, 1960, Use of a radioactive tracer for the measurement of sediment transport in The Netherlands. Proc. 7th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 445-454.

Taney, N. E., 1962, Laboratory applications of radioisotopic tracers to follow beach sediments. Proc. 8th Conf. Coastal Eng., Am. Soc. Civ. Eng., pp. 279-303.

Tashjian, Z., J. Cherry, G. Gordon and M. Gablinger, 1964, Radiometric determination of thorium in coastal sands for tracing littoral movement. Inst. of Eng. Res. Tech. Rept. Series HEL-5-3, Univ. California, Berkeley.

Watts, G. M., 1953, Development and field tests of a sampler for suspended sediment in wave action. Beach Erosion Board Tech. Memo. No. 34, 41 p.

Wright, F. F., 1962. The development and application of a fluorescent marking technique for tracing sand movements on beaches Columbia Univ., Dept. Geol. Tech. Rept. Project No. 388-057. p. 2.

Yasso, W. E., 1962, Fluorescent coatings on coarse sediments: an integrated system. Columbia Univ. Dept. Geol. Tech. Rept. Project No. 388-057, 19 p.

Yasso, W. E., 1964, Use of fluorescent tracers to determine foreshore sediment transport Sandy Hook, New Jersey, Off. Naval Res., Geog. Branch. Tech. Rept. Project No. 388-057, v. 6, 18 p.

Zenkovich, V. P., 1960, Fluorescent substances as tracers for studying the movement of sand on the sea bed: experiments conducted in the U.S.S.R. Dock Harbour Auth., v. 40, pp. 280-283.

Zenkovich, V. P., 1962, Application of luminescent substances for sand drift investigations in the nearshore zone of the sea. Ingenieur (Utrecht), v. 30, p. 3.

BEACH PROFILES AND ENVIRONMENTAL MEASUREMENTS

D. G. Aubrey
Scripps Institution
of Oceanography

The study of sediment transport in a region is incomplete without monitoring sand level changes and a variety of environmental parameters. This paper describes in a brief fashion the measurement of wind, barometric pressure, and water temperature, as well as the measurement and analysis of beach profile data.

Wind Measurements

There are a variety of methods available for measuring winds. A hand-held anemometer is the simplest of these. It yields an instantaneous estimate of wind speed; the wind direction must be estimated by other methods. The next step up in sophistication is an anemometer consisting of a weather vane with a propeller; the weathervane will point into the wind, while the rotation rate of the propeller is proportional to wind speed. This data is either put on an analog recorder, or voltage outputs from these sensors are noted visually. The statistics of these measurements depend on the sample rate of the instrument, and whether the instrument records instantaneous values or averages over time.

A new wind measuring system is being developed at Scripps Institution of Oceanography by Meredith Sessions. This system uses propeller type meters, similar to those used in the Davis-Weller current meters developed at SIO. These meters have excellent cosine responses. There are two sensors mounted orthogonally, from which the speed and direction of the wind can be deduced. A counter can be inserted in the instrument, so a long sample rate can be used to conserve space on the recording device, and any length averages can be taken. The counter will register a net wind flow for that sample interval. The sample interval can be adjusted to reflect the frequency range of interest. In its proposed configuration, the data can be recorded either digitally, or transferred directly to a computer.

Barometric Pressure

The barometric pressure is an important parameter if one wants to correct pressure sensor measurements made below the sea surface for atmospheric fluctuations. This is especially important if one is measuring small quantities such as wave set-down or storm surges. One cm of water depth is approximately equivalent to an atmospheric change of 0.08 cm of mercury. Since frontal activity and low pressure areas have much larger atmospheric pressure fluctuations than this, the barometric pressure must be accurately known to correctly reconstruct the sea surface elevation.

The normal method of monitoring barometric pressure relies on visual observations of a barometer at given time intervals. Since barometric pressure fluctuations are generally slow, this method is generally acceptable. However, at times of rapid pressure changes, a higher sample rate may be necessary. This is possible with a barometer which has a digital or analog output which can be sampled and stored on a mass storage device for later analysis.

Temperature Measurements

Ocean temperatures may be monitored for a number of reasons. For instance, the density and viscosity of water change with temperature. These variations may be important when considering the transport of sediment in the nearshore. Also, the temperature can be monitored to detect the passage of internal waves or their associated bores. In any case, the sample interval must be consistent with the frequency of motion of interest. Temperature measurement is generally based on one of four physical responses of materials (Winant, 1977): (a) thermal expansion of solids and liquids associated with changing temperatures (e.g., alcohol and mercury thermometers); (b) resistance to electron flow in conductors which is a function of conductor temperature (e.g., platinum wire resistance gage); (c) the mobility of electron and hole population in conductors and semi-conductors is temperature dependent (e.g., thermistors, thermocouples, or semi-conductors); and, (d) the wavelength of reflected light off certain substances may be temperature dependent (e.g., iochide crystals).

For remote or rapid readings, an electrical sampling system is desirable. For large quantities of data, a digital signal stored on a mass storage device is convenient for later data analysis.

<u>Beach Profiles and Analysis</u>

A primary measurement needed for studying sediment transport is the beach profile configuration. This configuration may indicate not only whether there have been net displacements of sediment, but also yields the beach slope which in part determines wave shoaling characteristics. There are a number of profiling techniques which have been tried. Stereo photography has been used, but is applicable only to subaerial portions of the beach, and lacks good vertical resolution. Horizon leveling is used for the subaerial part of the beach also, but it too has a limited accuracy. By far the most common method used to measure beach profiles is the engineer's level and rod, along with a measuring tape. This method is useful because it is possible to make measurements out to water depths of two to three meters, if the beach slope is not so small that the distances are prohibitive. This method has been shown to be very reliable (Aubrey, Inman and Nordstrom, 1976). Another, more expensive, method is to use a total station surveying system, such as the Hewlett-Packard Model 3810A total station. This system measures horizontal distance, elevation change, slope distance, zenith angle, and horizontal angle using a system of prism reflectors This system is only useful for the subaerial beach and very shallow water.

The offshore portion of the profile is more difficult to measure. Generally, the measurements are referenced to the sea surface (e.g., fathometer or pressure sensor). This generates uncertainties in the true mean level of the sea surface, since tides and water superelevations are not always accurately known. Inman (1953) developed a method which alleviated this problem by installing a series of brass reference rods on the bottom. Figure 1 is a schematic of his system. Sand level changes are then measured directly from the exposed portion of the reference rods, and the fathometer records can be more accurately calibrated. This still does not remove inaccuracies inherent in the fathometer. A lead line sounding, though taken carefully, still has the problem of referencing to the dynamic sea surface.

A sub-bottom profiler can be used to measure changes in sand thicknesses where bedrock underlies the beach sand. A high resolution system is needed, however, and a large power requirement exists because of the high level of volume reverberation and energy losses in the sand (Gordon, 1974). Consequently, an expensive and bulky system is required and is not practical for most purposes.

Another method has been suggested by Seymour (1977). This consists of an inertial guidance system mounted on a movable sled. If this sled is started from a known location with a known elevation, the subaerial and subaqueous beach can be profiled, even in the vicinity of the breakpoint. No present methods can consistently and accurately measure profiles under large breaking waves.

A useful analytical tool for beach profile data is the method of empirical eigenfunctions. This approach has been used by Winant, Inman and Nordstrom (1975) and Winant and Aubrey (1976) to characterize the primary modes of beach profile variability. Figures 2-4 show the spatial dependence of the three eigenfunctions associated with the three largest eigenvalues for various data sample lengths. Figure 5 shows the temporal dependence of these eigenfunctions.

Since the general shape of the spatial functions is not dependent on the length of the data set, as shown in Figures 2-4, it appears that these functions characterize physically meaningful and stable quantities. Figure 6-8 show the same eigenfunctions evaluated for only the subaerial beach. The spatial dependence is nearly identical to that of the combined subaerial-subaqueous profiles, so the first three eigenfunctions appear to indeed characterize physically meaningful seasonal and short term profile changes. The advantage of this eigenfunction method is that only a few functions can be used to characterize large volumes of profile data, and the modes of variability are all uncorrelated.

References

Aubrey, D. G., D. L. Inman and C. E. Nordstrom, "Beach profiles at Torrey Pines, California ", Proc. 15th Int. Conf. on Coastal Eng., Amer. Soc. Civil Eng., 15 pp., 1976.

Gordon, L., 1974 unpublished report, "Subbottom profiler", SIO Shore Processes Laboratory, 14 pp.

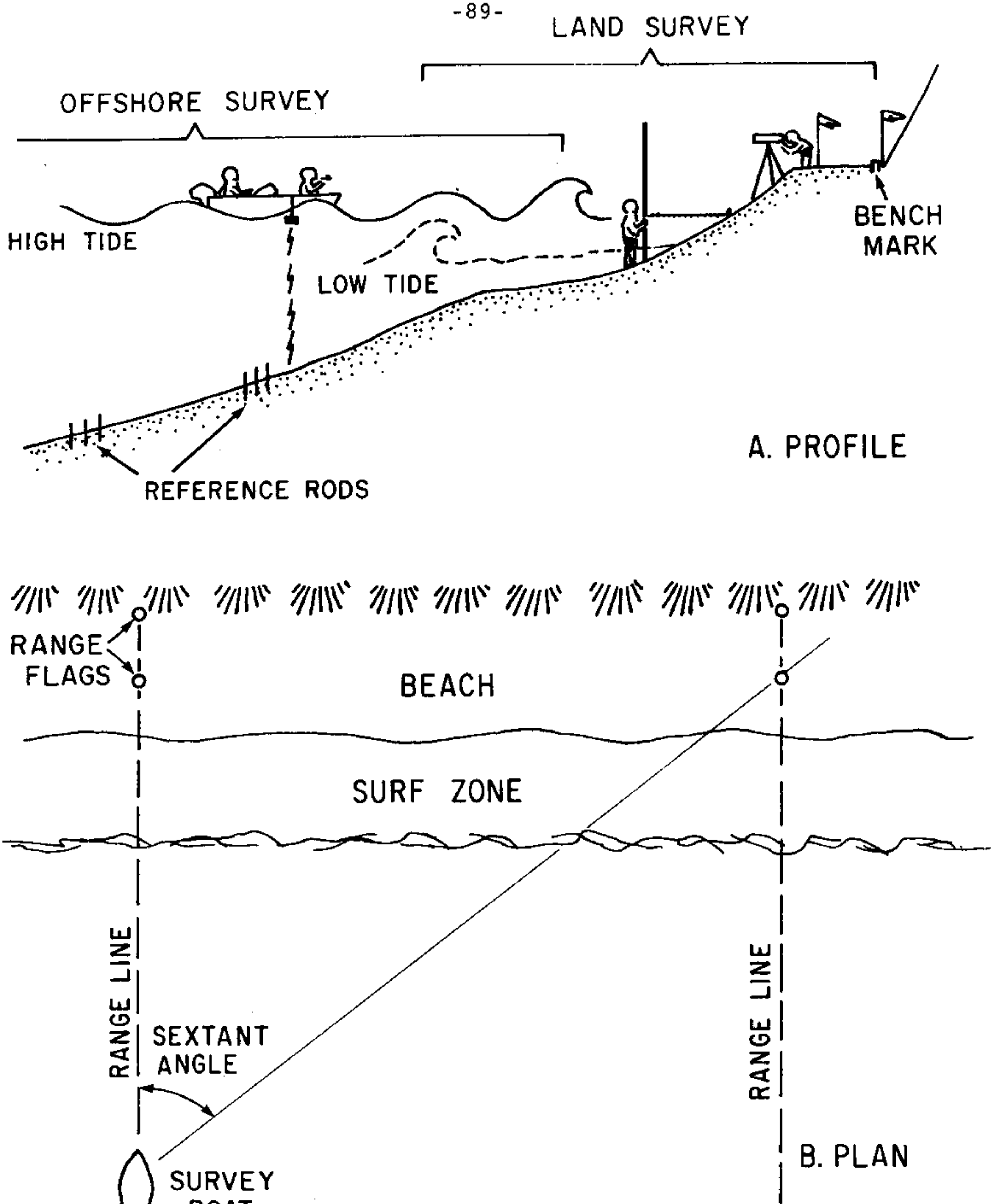
Inman, D. L., 1953, "Areal and seasonal variations in beach and nearshore sediments at La Jolla, California", U. S. Army Corps of Eng., Beach Erosion Board Tech Memo 39, 82 pp.

Seymour, R. J., 1977, "Field investigations of on and offshore sediment transport", proposal.

Winant, C. D., 1977, "Temperature measurements", Class Notes for SIO 215 Spring.

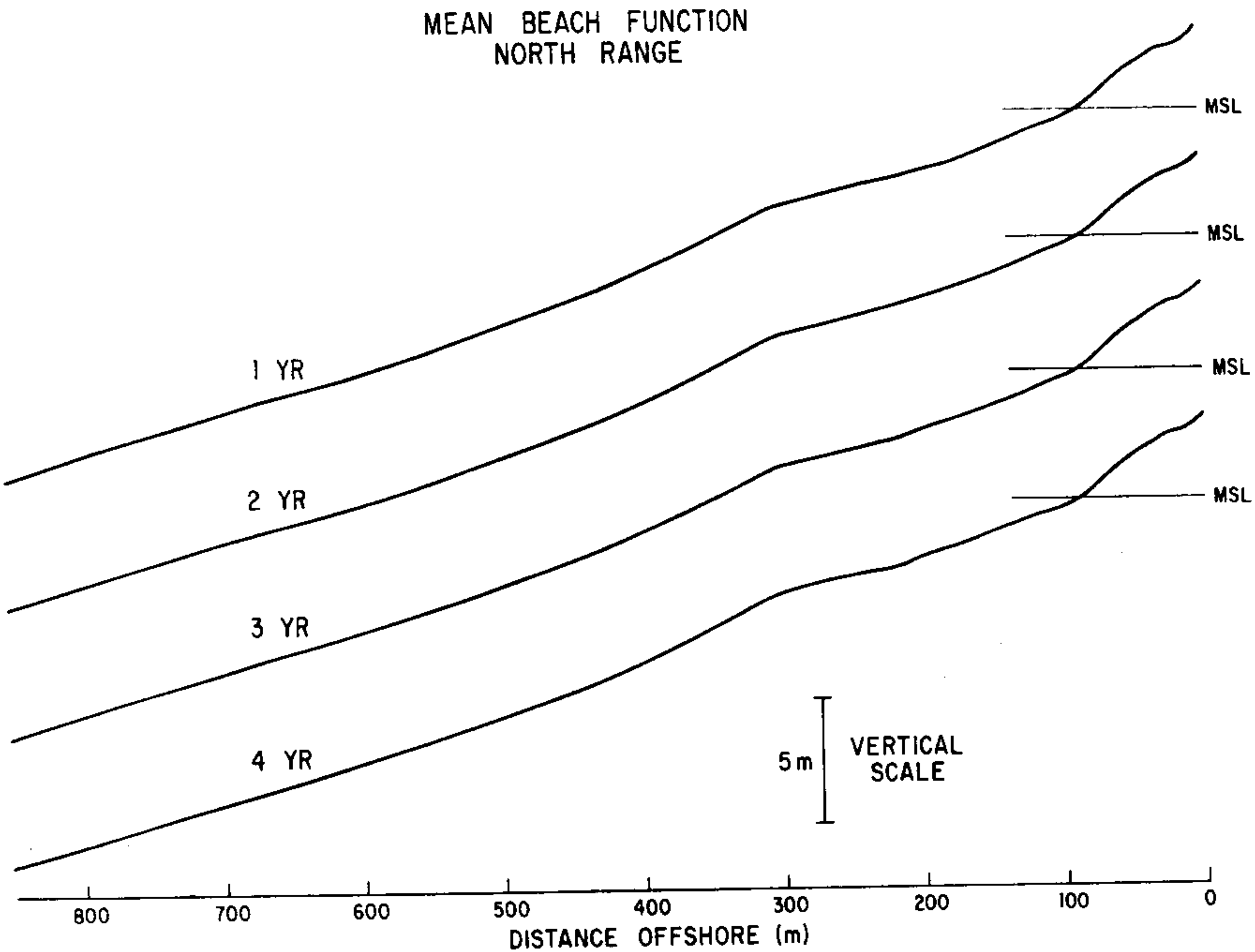
Winant, C. D., D. L. Inman and C. E. Nordstrom, 1975, "Description of seasonal beach changes using empirical eigenfunctions", Jour. Geophys. Res., vol 80, no 15, p 1979-86.

Winant, C. D. and D. G. Aubrey, 1976, "Stability and impulse response of empirical eigenfunctions", Proc. 15th Int. Conf. on Coastal Eng., Amer. Soc. Civil Eng., 14 pp.



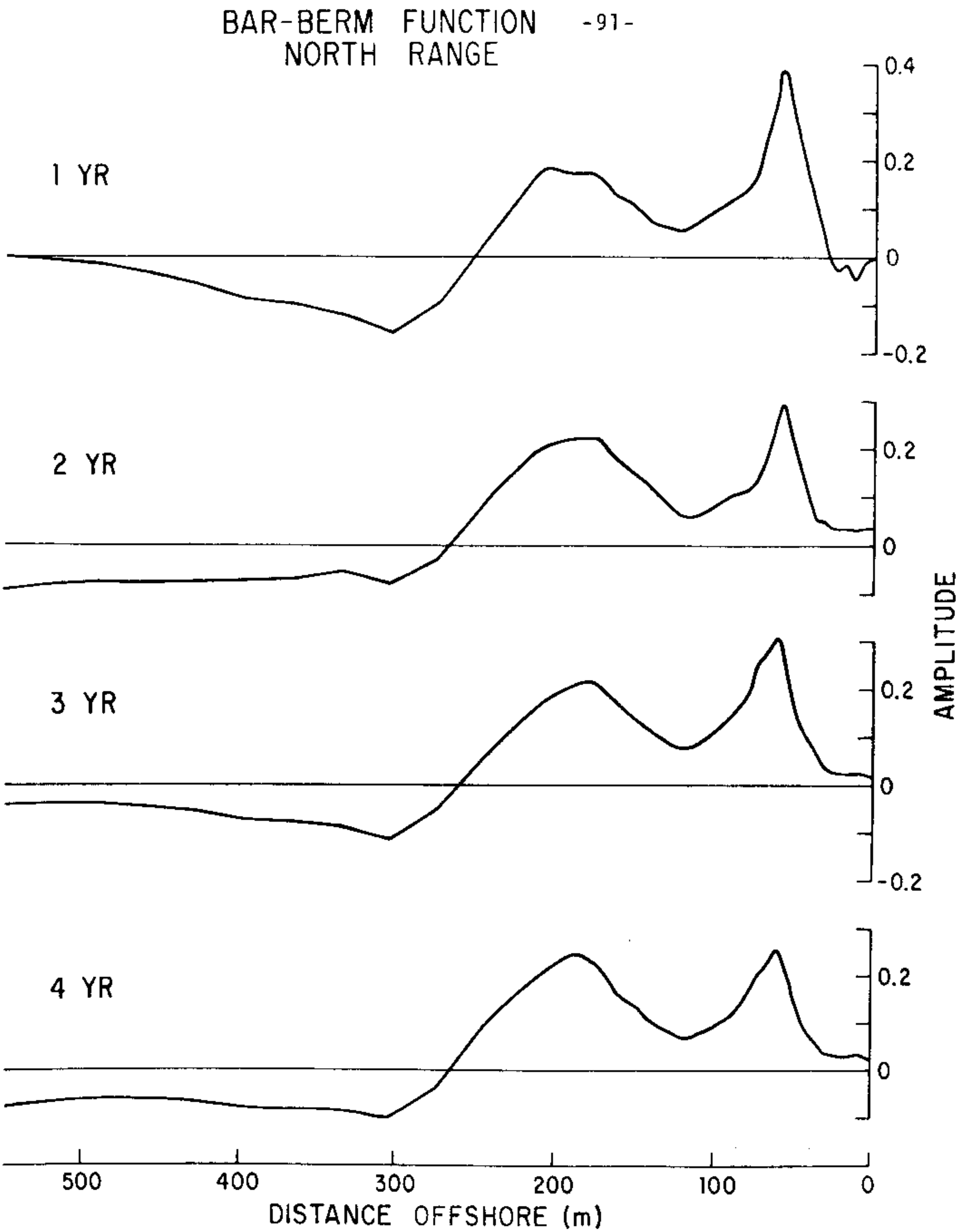
74-122-2

Figure 1. Schematic of possible profile survey procedure.



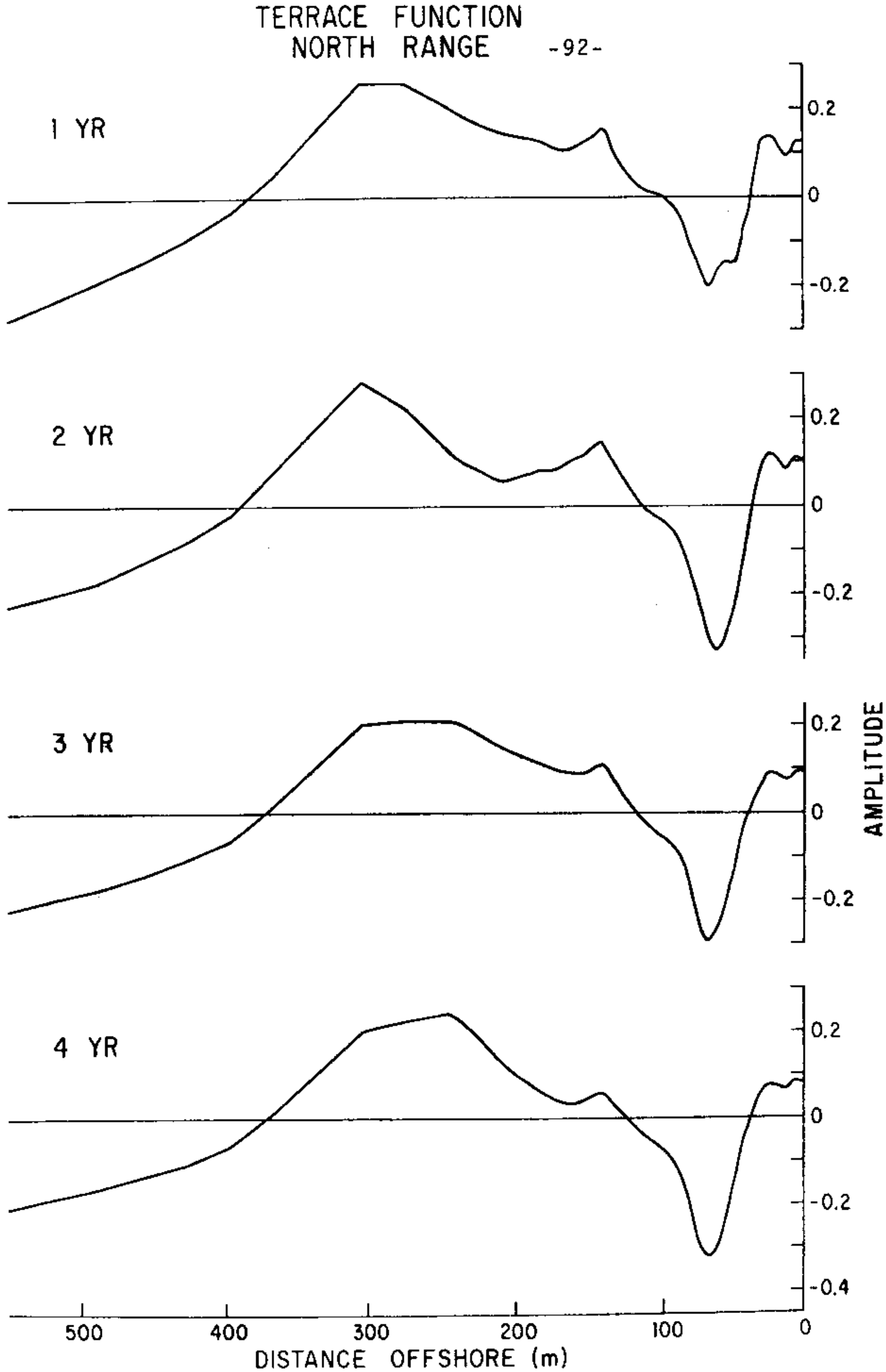
76-23-10

Figure 2. Spatial dependence of the mean beach function for data sets of 1, 2, 3, & 4 years length.



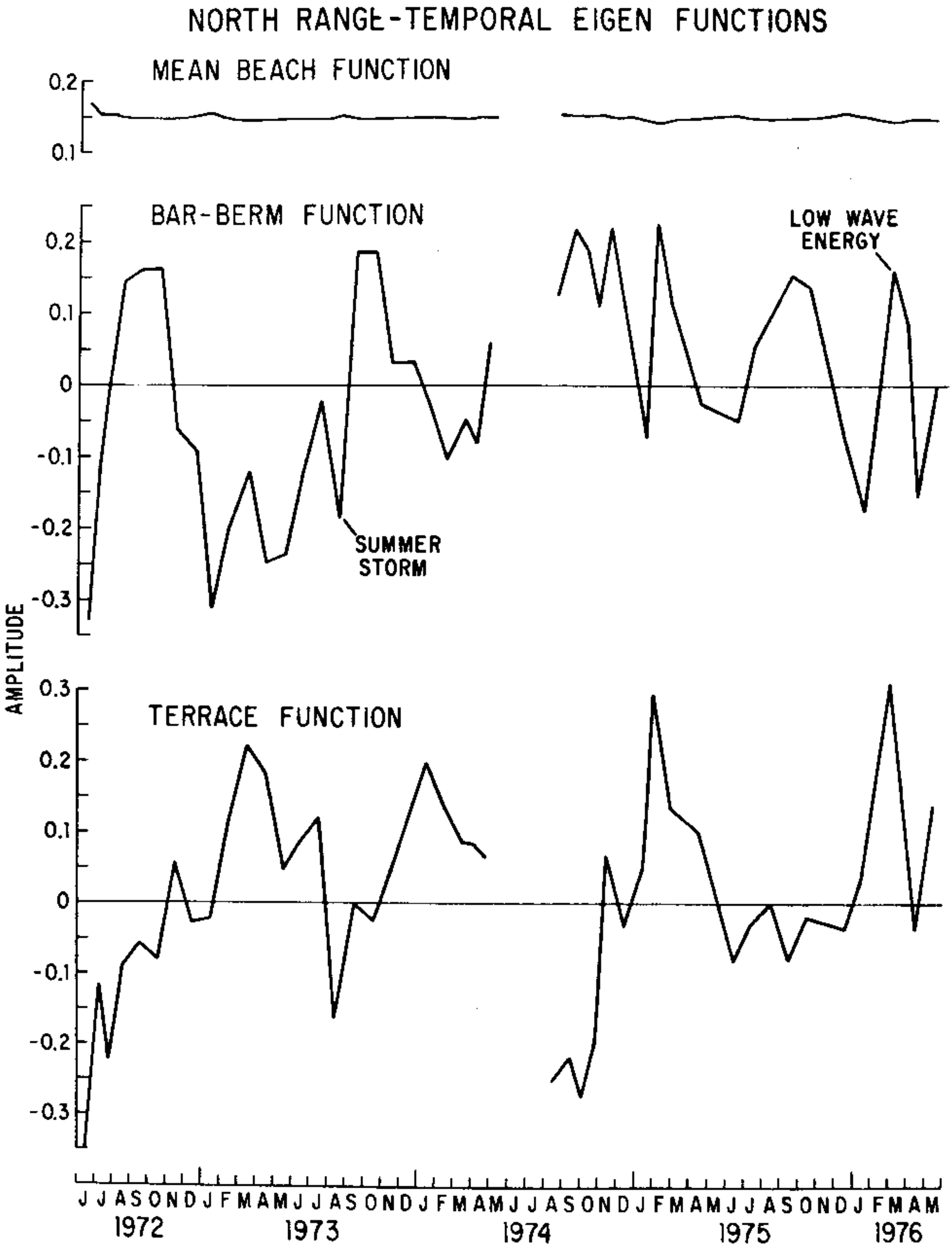
76-23-12

Figure 3. Spatial dependence of the bar-berm function for data sets of 1, 2, 3, & 4 years length.



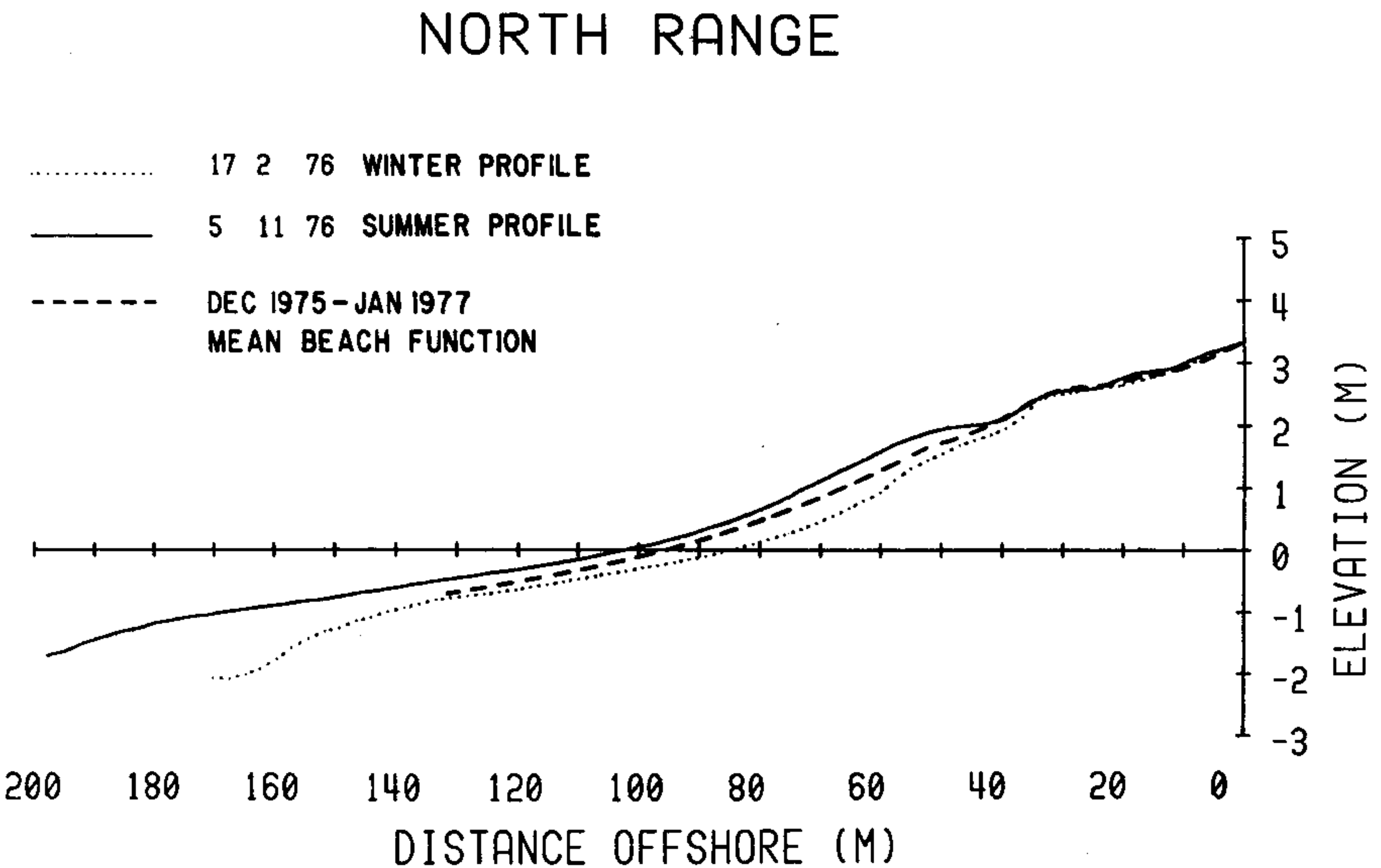
76-23-11

Figure 4. Spatial dependence of the terrace function for data sets of 1, 2, 3, & 4 years length.



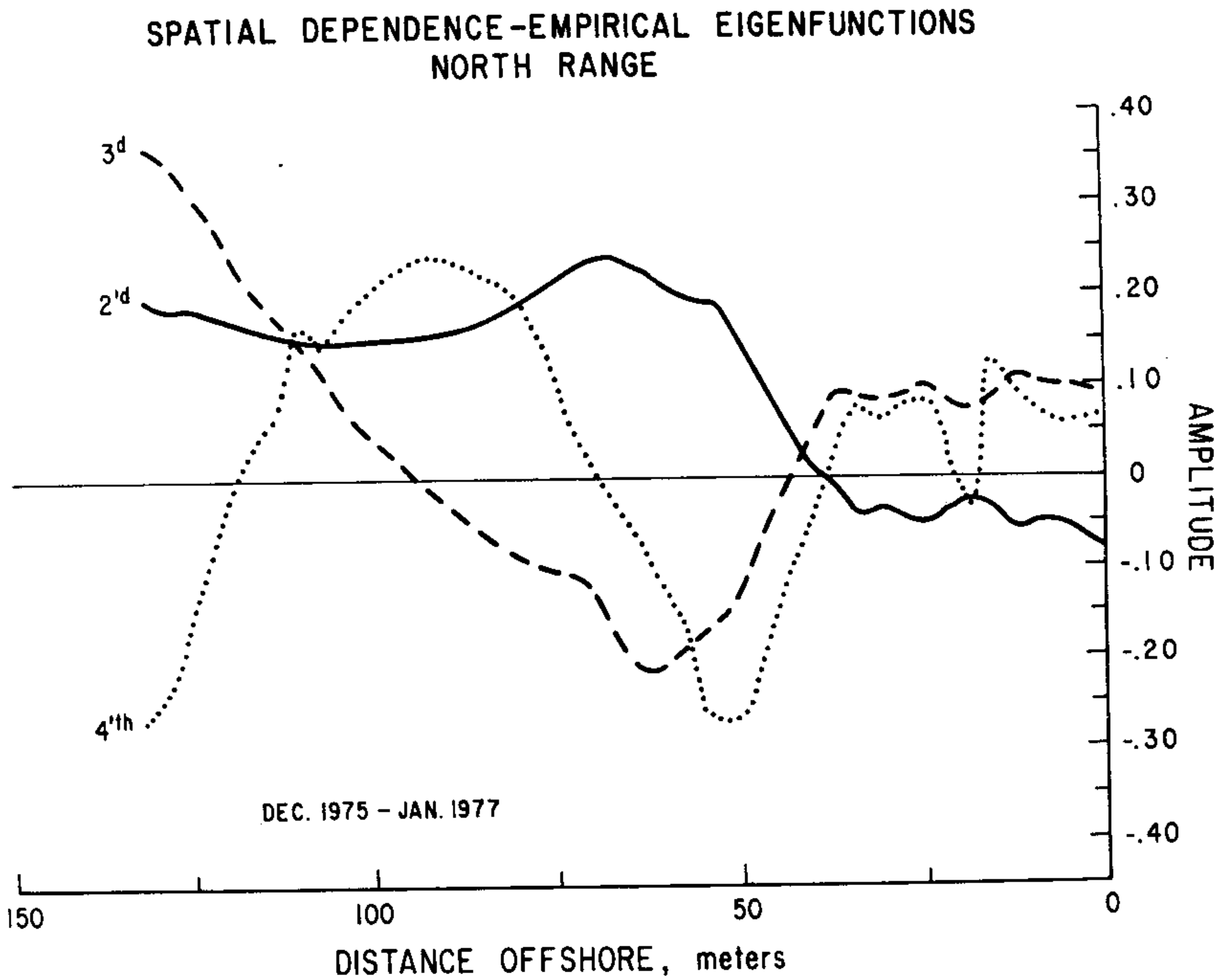
76-23-2

Figure 5. Temporal dependence of the first three eigenfunctions for a four year data set.



77.55-14

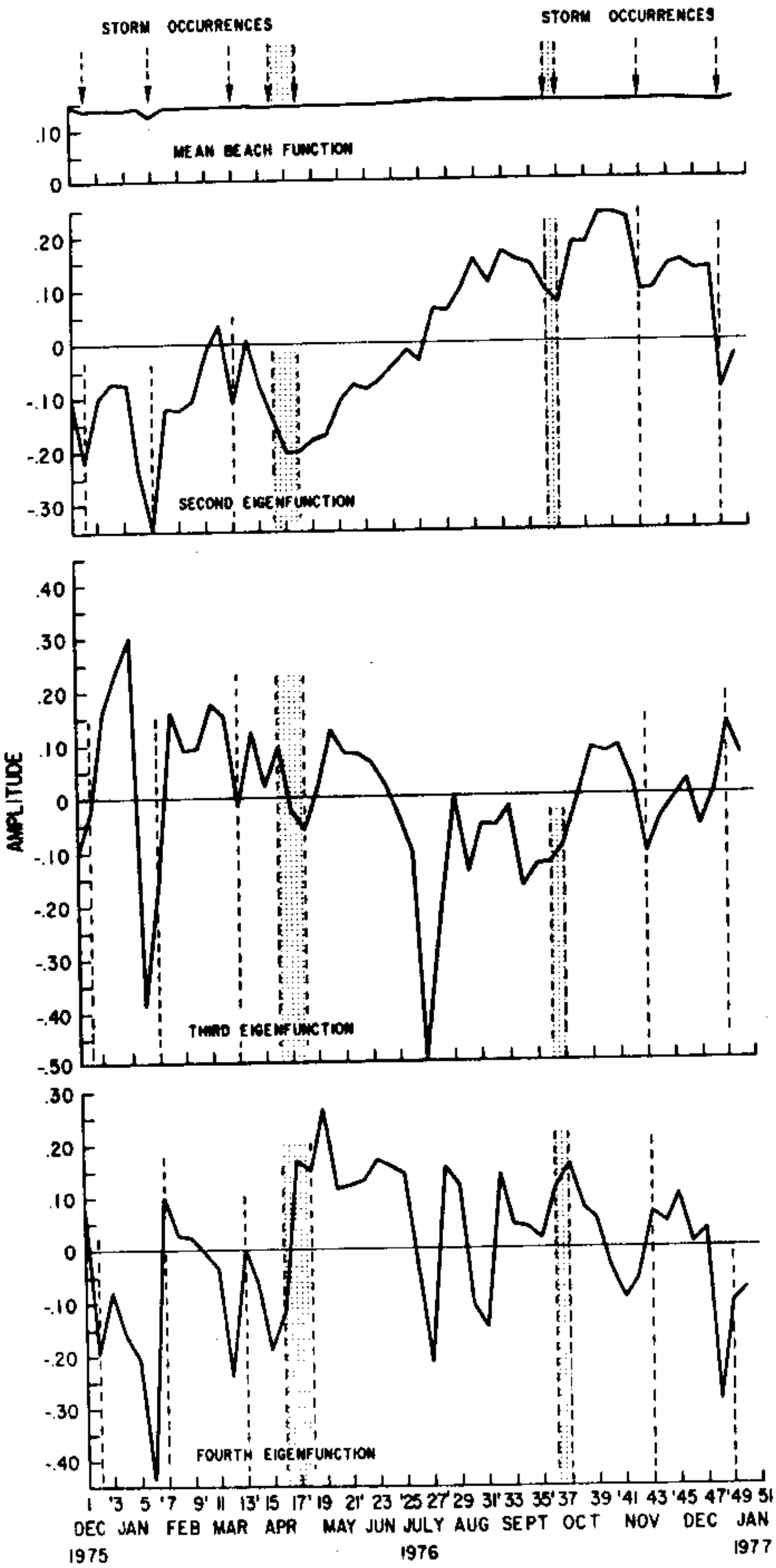
Figure 6. Spatial dependence of the mean beach function along the beach foreshore.



77-55-11

Figure 7. Spatial dependence of the 2nd. 3rd. & 4th eigenfunctions along the beach foreshore.

TEMPORAL DEPENDENCE-EMPIRICAL EIGENFUNCTIONS NORTH RANGE



77·55-7

Figure 8. Temporal dependence of the first four eigenfunctions for a one-year data set.

LINEAR ARRAYS

S. S. Pawka
Scripps Institution
of Oceanography

Introduction

Linear and two-dimensional arrays have been used by many investigators for the estimation of the directional spectrum of wind generated waves. Both types of arrays have the sampling problems of central peak resolution and aliasing which cause trade-offs in the array design. Linear arrays maximize the total length of the array for a minimum aliasing criterion. Linear arrays also have the advantage that they may be aligned with the depth contours to avoid refractional effects. This is not possible with a two-dimensional array on a sloping shelf.

The disadvantages of linear arrays include very poor resolution of waves propagating parallel to the array and total directional ambiguity for angles reflected through the array's axis. Therefore, linear arrays should only be used in areas which have only two quadrants of possible wave approach. It is also useful to have the array aligned perpendicular to the expected approach angle of the waves. Linear arrays are of particular use when aligned along a depth contour reasonably close to a straight segment of coastline. It is necessary that wave reflection from the coast be negligible for this design to be of practical use. In addition to the work cited in the text,the bibliography lists references which document field experience with linear and two-dimensional arrays and associated time series problems.

Array Design

Directional information is derived from an array through the measurement of the variation of the wave cross-spectrum as a function of sensor separation.

Therefore, it is desired to maximize the number of spatial "lags" available. Figure 1 is a plot of the beam pattern (Barber, 1963) of a 4 sensor linear array for waves of 14 second and 4 second periods. These curves represent the response of the array to a unidirectional wave normally incident to the array. The poor central peak resolution of the 14-second waves is due to the relatively short length of the array compared to the wavelength. The high alias lobes in the 4-second response represent a directional ambiguity and are due to the large size of the unit spacing relative to the 4-second wavelength. The design of an array will generally have these two problems representing trade-offs in array dimensions.

The parameters which may be varied in the design of a linear array include: (1) relative spacings of sensors; (2) number of sensors; (3) total length of array; (4) depth of sensors; and (5) orientation of the array. Barber (1958) suggested a scheme for optimal spacings for line arrays with various numbers of sensors. These arrays have the property that they maximize the number of consecutive integer multiple lags available with a given number of sensors. The relative spacings of the elements of several of these arrays is listed in the table below:

NUMBER OF SENSORS	RELATIVE SPACINGS	TOTAL ARRAY LENGTH
3	1-2	3 N
4	1-3-2	6 N
5	1-3-3-2	9 N
6	1-1-4-4-3	13 N
7	1-1-4-4-4-3	17 N

N is the unit spacing. Stevens (1965) utilized a sensor linear array designed as suggested above. Gilchist (1966) employed a 7-sensor array arranged with these 'optimal' spacings. The 3 and 4 sensor arrays shown above are optimal in that they maximize the resolution of the array for a given aliasing criterion. This is not true for the arrays which have at least 5 sensors. These arrays all have redundant lags and it is possible to design arrays which have better aliasing characteristics for the same array length. The windows plotted in Figure 2 show the beam pattern of 1-3-3-2 and 1-2-4-5 relative spacing arrays of equal length. The aliasing condition is present only in the response function of the 1-3-3-2 array. Figure 3 is a plot of the mean squared window error for a 1-3-3-2 and 1-2-4-5 arrays. The 1-3-3-2 array has better window properties for the longer waves but shows an earlier occurrence of the large errors due to aliasing in the higher frequencies. Figure 4 shows the percentage errors in the calculation of $\sin\alpha\ \cos\alpha$ (following Dean, 1974), due to the windows of the 1-3-3-2 and 1-2-4-5 arrays. The aliasing problems for the higher frequency waves can cause the estimate of the drift to be in the wrong direction.

It is apparent that there is no universal optimal arrays for systems with many sensors. The design is a strong function of the expected wave conditions. For example, one may be working in an area with a characteristic spectrum containing two modes, one very long period component and short-period, locally generated waves. In this case, one might use an array which is composed of two sub-arrays which have different scale dimensions but have some sensors in common. This was done in the JONSWAP Experiment, Hasselmann, et al (1973).

The condition of no aliasing (for the two quadrants of possible wave propagation) requires that the minimum spacing of the Barber designs be at most $L/2$ where L is the wavelength of the shortest wave of interest. To increase the resolution with this constraint requires a longer array and thus more sensors. Figure 5 is a plot of window width versus total length of the array and shows a region of diminishing marginal benefit as the array length is large relative to the wavelength.

The table below shows the dimensions of an array designed for a single frequency and the associated resolution.

SENSORS	SPACINGS	LENGTH OF ARRAY	RESOLUTION (APPROX.)
3	1-2	1.5 L	20^0
4	1-3-2	3.0 L	10^0
5	1-3-3-2	4.5 L	7^0
6	1-1-4-4-3	6.5 L	5^0
7	1-1-4-4-4-3	8.5 L	4^0

L is the wavelength.

The depth of a linear array is often constrained by the sensors used. Due to the exponential decay of the pressure field with depth, it is necessary to have an array of bottom mounted pressure sensors in a depth which is shallow relative to the deep water wavelength of the shortest waves to be measured. However, the breaker zone with its associated strong non-linearities must be avoided for meaningful measurement of directional spectra. In general, along a plane contour beach a shallow array is desirable because the waves are refracted towards normal incidence, which is the angle of best resolution of the linear array (Figure 6). However, complicated topography may require a deeper array to avoid refraction problems.

Analysis Techniques

The windows that have been discussed thus far are associated with an estimator which is the direct spatial Fourier transform of the wave cross spectrum function. The information from the various lags may be relatively weighted to alter these windows to some extent. The lags may be weighted to reduce the side lobs of the windows or eliminate the negative energy estimates. However, these alterations can be made only at the expense of poorer central peak resolution (for fixed lag coefficient estimators). Dean (1974) showed that for the calculation of $\sin\alpha\cos\alpha$ for a unidirectional input, the Barber window (equal weights of lags) was a better estimator than the W_2 weighting scheme (Panicker, 1971) which has no negative lobs.

Higher resolution techniques have been developed that utilize the data to minimize the window error. Panicker (1974) discusses two of these "data adaptive" estimators. More comprehensive treatments can be found in Regier (1975) and Kanasewich (1975). The maximum likelihood method (MLM) introduced by Capon (1969) does a much better job of estimating narrow distributions than the Barber window, (Figure 7). The estimates of $\int S(\alpha)\sin\alpha\cos\alpha\, d\alpha$ show much better results than the Barber window for a distribution $S(\alpha) = A\cos^4(\alpha - \alpha_0)$. However, as pointed out by Regier (1975) the MLM over-resolves very broad directional spectra. This is reflected in the poorer estimates of $\int S(\alpha)\sin\alpha\cos\alpha\, d\alpha$ for the distribution $S(\alpha) = A\cos^4(\alpha - \alpha_0)$. The percentage error of these estimates are shown in the table below. Knowledge of the type of wave spectra expected is useful in the decision on what type of estimator to be employed.

ESTIMATOR	ARRAY	M	10	20	30°	40	50	60	70
Barber	1-2-4-5	400	7.4	2.2	-15.5	7.1	8.8	-28.1	-30.0
Barber	1-3-3-2	400	-5.7	8.7	-8.1	8.2	5.1	-18.4	-16.5
MLM	1-2-4-5	400	0.5	0.9	0.6	0.6	0.6	1.9	3.5
MLM	1-2-4-5	4	29.9	26.7	21.9		11.4	6.3	2.9

The values given are percentage errors in the calculation of $\int S(\alpha)\cos\alpha\sin\alpha\, d\alpha$ for $S(\alpha) = A\cos^M(\alpha - \alpha_0)$. The analysis was done for a wavelength $L = 4.19$ when ℓ is unit spacing.

APPENDIX I DEFINITIONS

The derivations and mathematical definitions of the relationships used in the text were not included because it was desired to present only a brief discussion of the important factors of array design. However, to avoid possible ambiguity the relationships used to generate the plots and data in the report are defined below:

(1) $G(\alpha, \alpha_0, f)$: the fixed lag spectral window

$$G(\alpha, \alpha_0, f) = \sum_{n=-N}^{N} a_n \cos\left[\frac{2\pi \ell(n)}{L} (\mathrm{Sin}\,\alpha - \sin\alpha_0)\right]$$

where n are lags, $\ell(n)$ are spacings of lags, α is the direction relative to normal to array, α_0 is the direction of input, L is the wavelength, and a_n are weights.

The "Barber window" is defined with $a_n = 1$ for all available lags.

(2) $S(\alpha, f)$: the Barber estimator of directional spectrum

$$S(\alpha, f) = S_0(f) + \sum_{n=1}^{N} 2\cdot\left\{C_n(f) \cos\left[\frac{2\pi \ell(n)}{L} \sin\alpha\right] + Q_n(f)\sin\left[\frac{2\pi \ell(n)}{L} \sin\alpha\right]\right\}$$

where $S_0(f)$ is the energy density of frequency f, and $C_n(f) - iQ_n(f)$ is cross-spectrum of sensors separated by lag n.

(3) $P(\alpha, f)$: the maximum likelihood estimate of directional spectrum

$$P(\alpha, f) = \left\{ \sum_{m, n = 1}^{N} Q_{mn}^{-1} \, e^{-\left[\frac{2\pi i \ell(m, n)}{L} \sin\alpha\right]} \right\}^{-1}$$

where Q_{mn}^{-1} is the inverse of the cross-spectral matrix.

(4) $D(\alpha_0, f)$: mean square deviation of window from a delta function:

$$D(\alpha_0, f) = \int_{-\pi/2}^{\pi/2} \left[\delta(\alpha - \alpha_0) - W(\alpha - \alpha_0)\right]^2 d\alpha$$

where $\delta(\alpha - \alpha_0)$ is a linear delta function.

(5) ε: percentage error in calculation of drift function

$$\varepsilon = \left\{ \frac{\int_{-\pi/2}^{\pi/2} \hat{S}(\alpha) \cos\alpha \sin\alpha \, d\alpha}{\int_{-\pi/2}^{\pi/2} S(\alpha) \cos\alpha \sin\alpha \, d\alpha} \right\} \times 100$$

where $S(\alpha)$ is the model spectrum and $\hat{S}(\alpha)$ is the estimate.

REFERENCES

Barber, N. F., 1963, "The directional resolving power of an array of wave detectors", Ocean Wave Spectra, Prentice-Hall, Englewood Cliffs, New Jersey, p 137-156.

Capon, J., 1969, "High resolution frequency-wavenumber spectrum analysis", Proc. IEEE, vol 57, p 1408-1418.

Dean, R. G., 1974, "Directional wave spectra: some application and storage", Proc. Int. Symp. on Ocean Wave Measurement and Analysis, New Orleans, La.

Kanasewish, E. R., 1975, Time Sequence Analysis in Geophysics, University of Alberta Press, Alberta, 364 pp.

Panicker, N. N., 1974, "Review of techniques for wave spectra", Proc. Int. Symp. on Ocean Wave Measurement and Analysis, New Orleans, La.

Regier, L. A., 1975, "Observations of the power and directional spectrum of oceanic surface waves", Ph. D. Dissertation, Univ. of Calif., SIO, 176 pp.

Linear Arrays

Barber, N. F., 1958, "Optimum arrays for direction finding", New Zealand Jour. of Sci., vol 1, no 1, p 35-51.

Gilchrist, A. W. R., 1966, "The directional spectrum of ocean waves: an experimental investigation of certain predictions of the Miles-Phillips Theory of Wave Generation", Jour. Fluid Mech., vol 25, part 4, p 795-816.

Hasselmann, K. and J. P. Barnett, 1973, "Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP), Erganzungsheft Zur Deutschen Hydrographischen Zeitschrift, Reihe A, vol 8, no 12.

Pawka, S. S., D. L. Inman, R. L. Lowe and L. C. Holmes, 1976, "Wave climate at Torrey Pines Beach, California", Tech Paper No 76-5, Coastal Engineering Research Center.

Stevens, R. G., 1965, "On the measurement of the directional spectra of wind generated waves using a linear array of surface elevation detectors", unpublished manuscript, Ref No 65-20, Tech Report WHOI, Woods Hole, Mass.

Two-Dimensional Arrays

Bennett, C. M., 1965, "A directional analysis of sea waves from bottom pressure measurements", Trans. Nat. Symp. on Ocean Sciences of the Atlantic Shelf, Marine Technology Society.

Mobarek, I. E., 1965, "Directional spectra of laboratory wind waves", Proc. ASLE, Jour. Waterways and Harbors Division, vol 91, no WW3, p 91-116.

Munk, W. H., G. R. Miller, F. E. Snodgrass and N. F. Barber, 1963, "Directional recording of swells from distant storms", Roy. Soc. London, Phil. Trans., Series A, vol 255, no 1062, p 505-584.

Panicker, N. N. 1971, "Determination of directional spectra of ocean waves from gage arrays", Tech Report HEL 1-18, Univ. of Calif., Hyd. Eng. Lab. Berkeley.

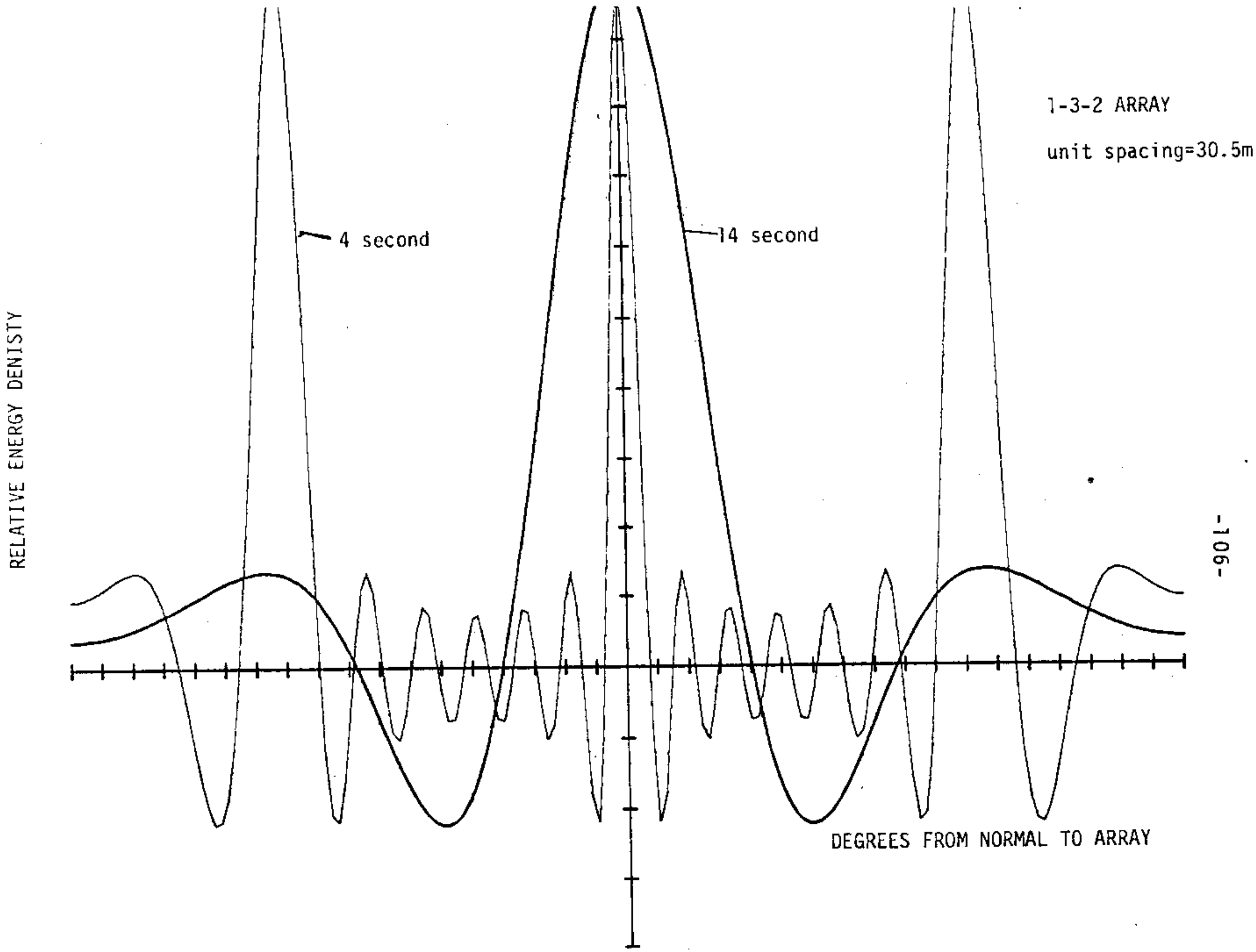


Figure 1. Beam pattern (see Appendix 1) of the 1-3-2 array for 14 second and 4 second wave periods in 10 meters of water.

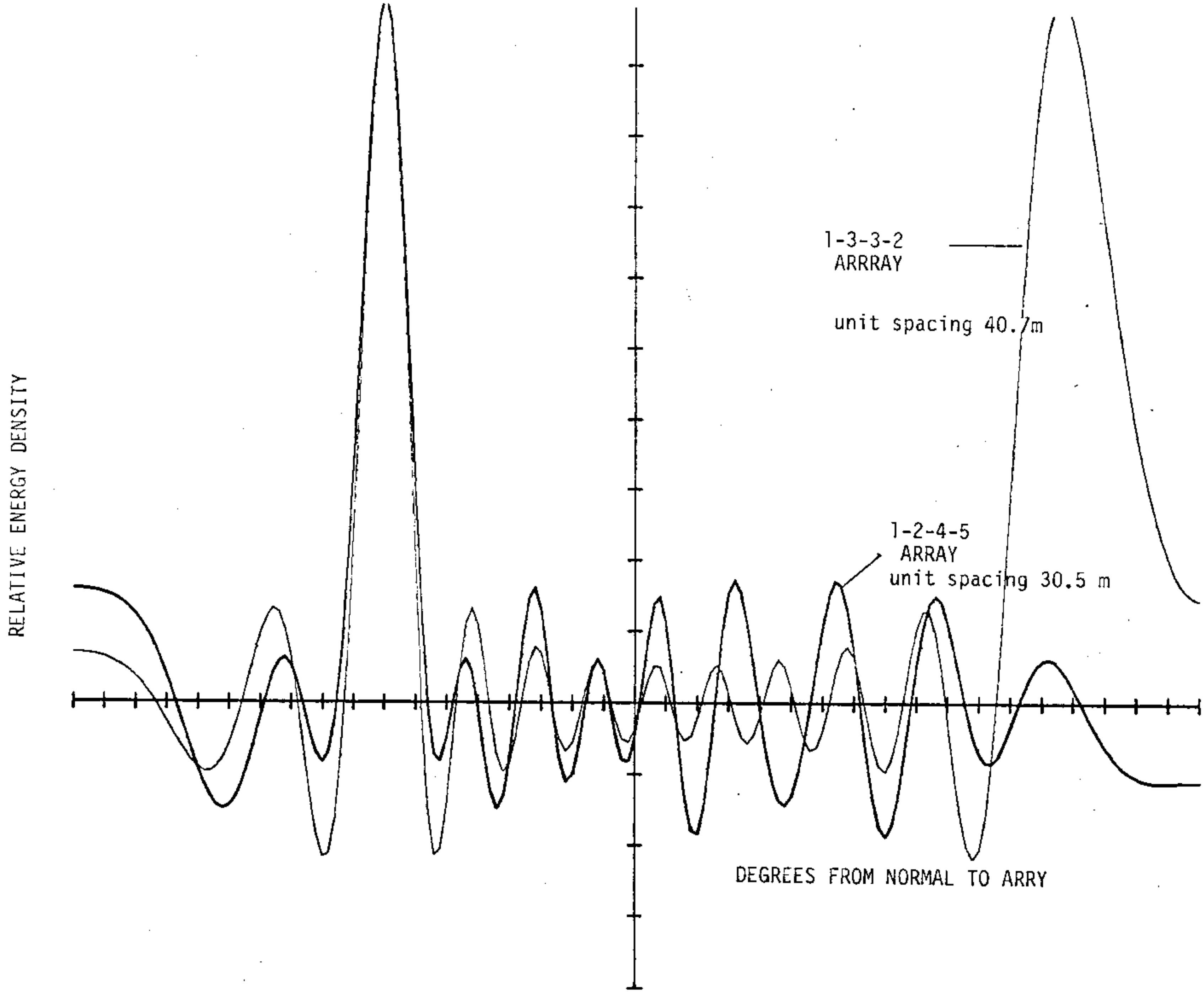
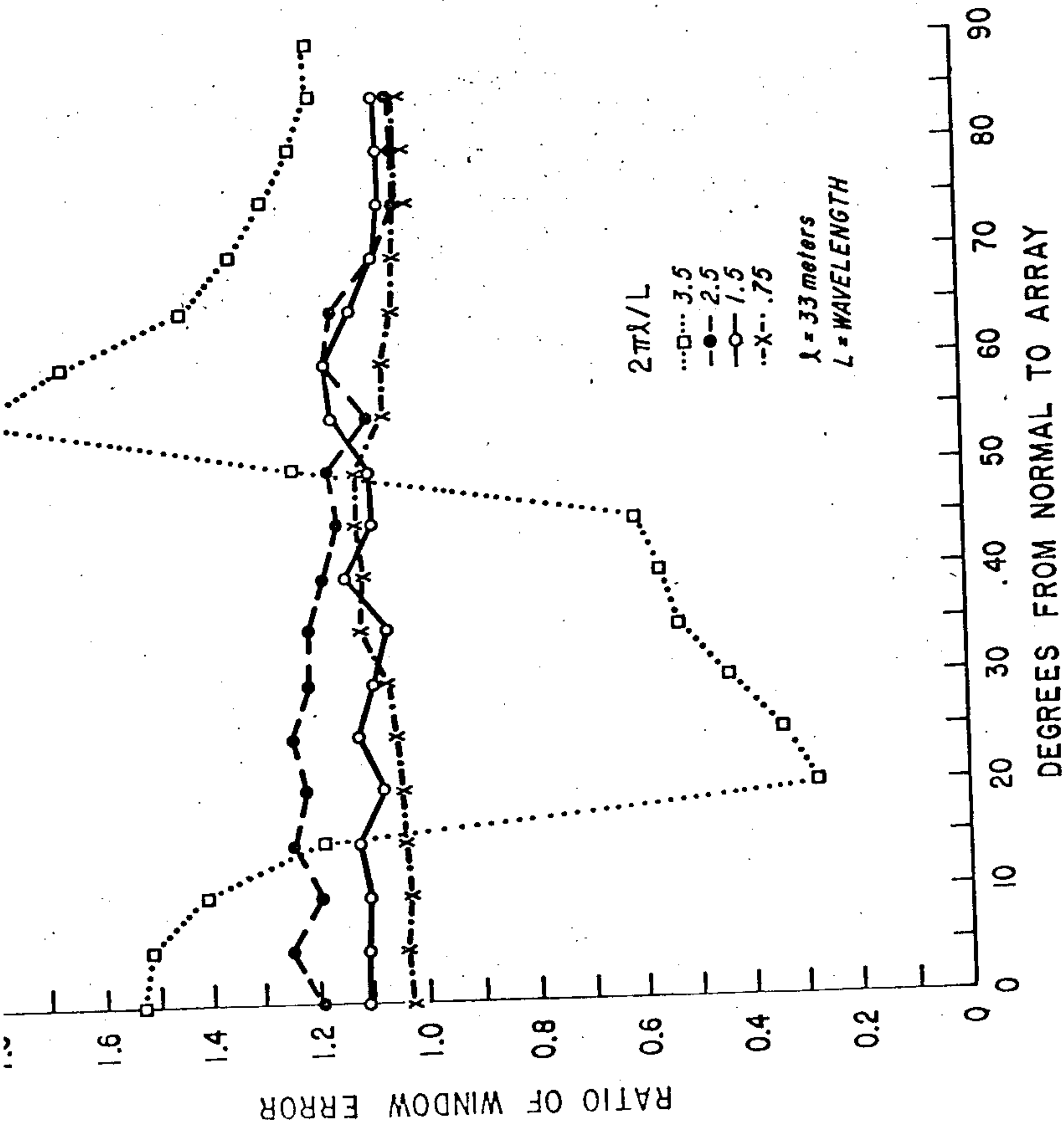


Figure 2. Response of 1-3-3-2 and 1-2-4-5 arrays of the same length to 7.3 second waves in 10 m depth. The 67^{o} peak for the 1-3-3-2 array is due to aliasing.

Figure 3. The ratio of window error of two five sensor arrays (1-2-4-5/1-3-3-2). The window error is defined as the mean square deviation of the window from a Dirac delta function (see Appendix 1).



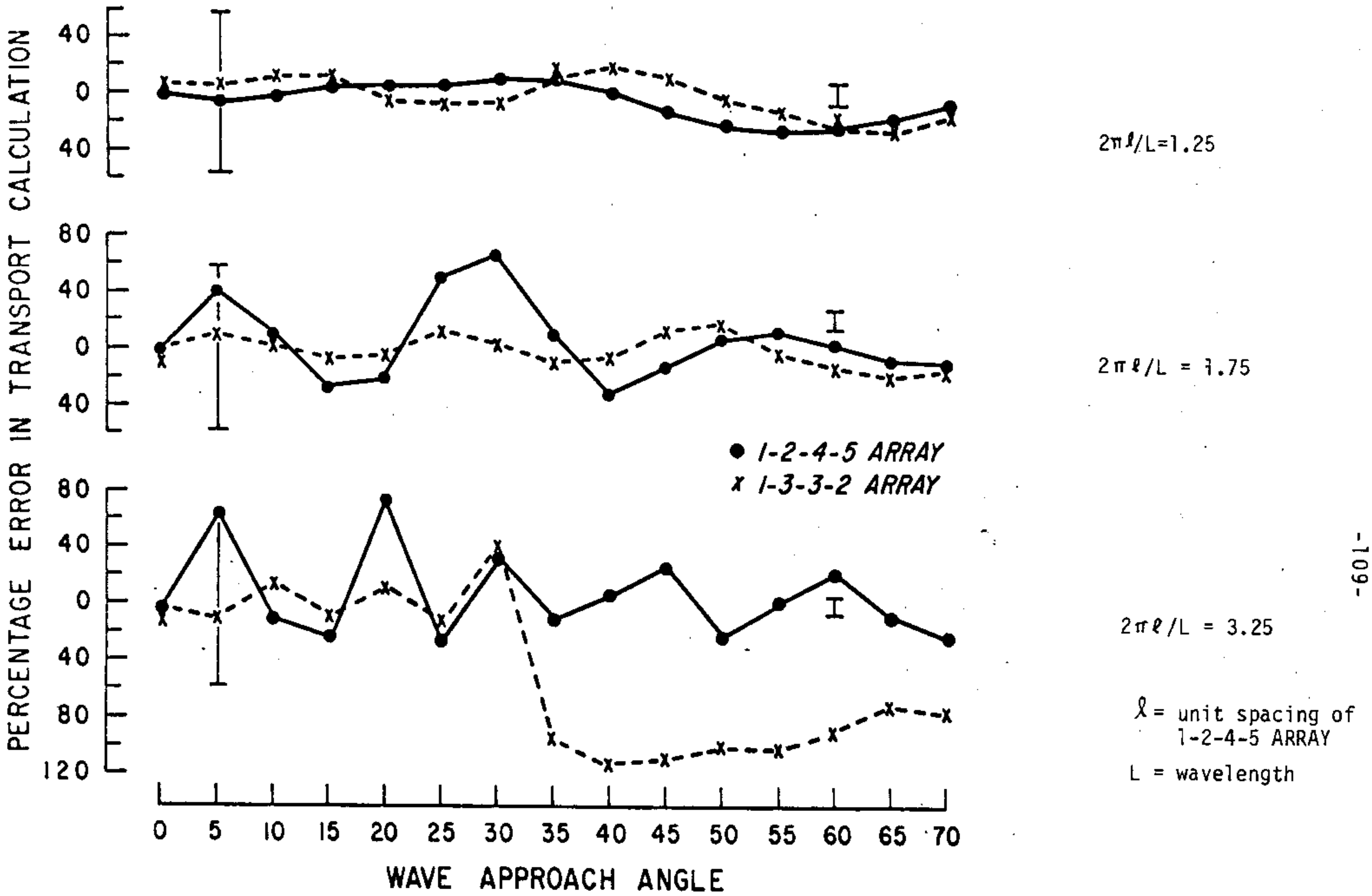


Figure 4. The percentage error in the calculation of $\int \hat{S}(\alpha) \sin\alpha \cos\alpha \, d\alpha$ with a unidirectional source. The estimates, $\hat{S}(\alpha)$, were made using a rectangular lag window (Barber, 1963) with the lags from the 1-3-3-2 and 1-2-4-5 arrays.

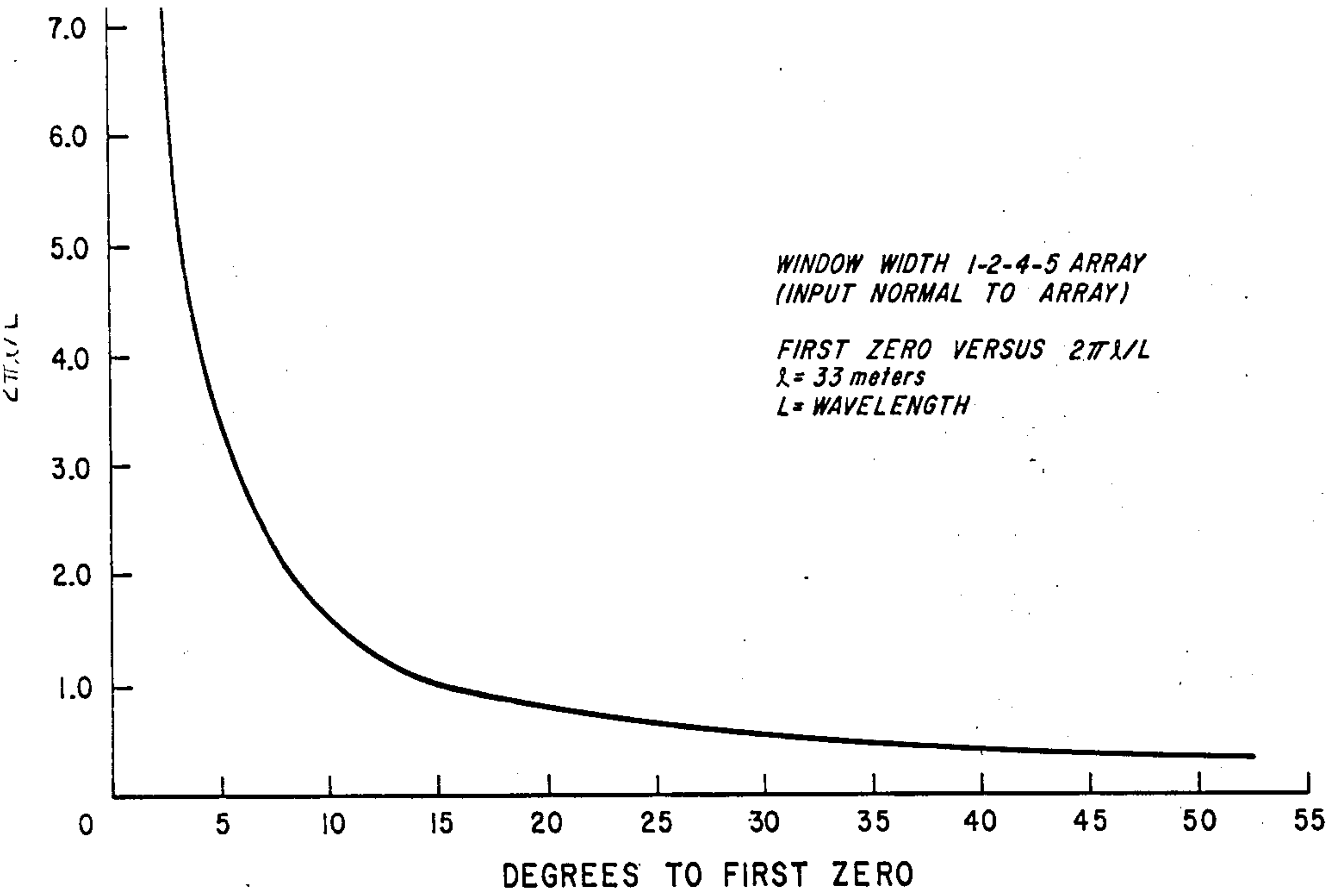


Figure 5. Width of the beam pattern for normal incidence as a function of ratio of unit lag spacing to wavelength.

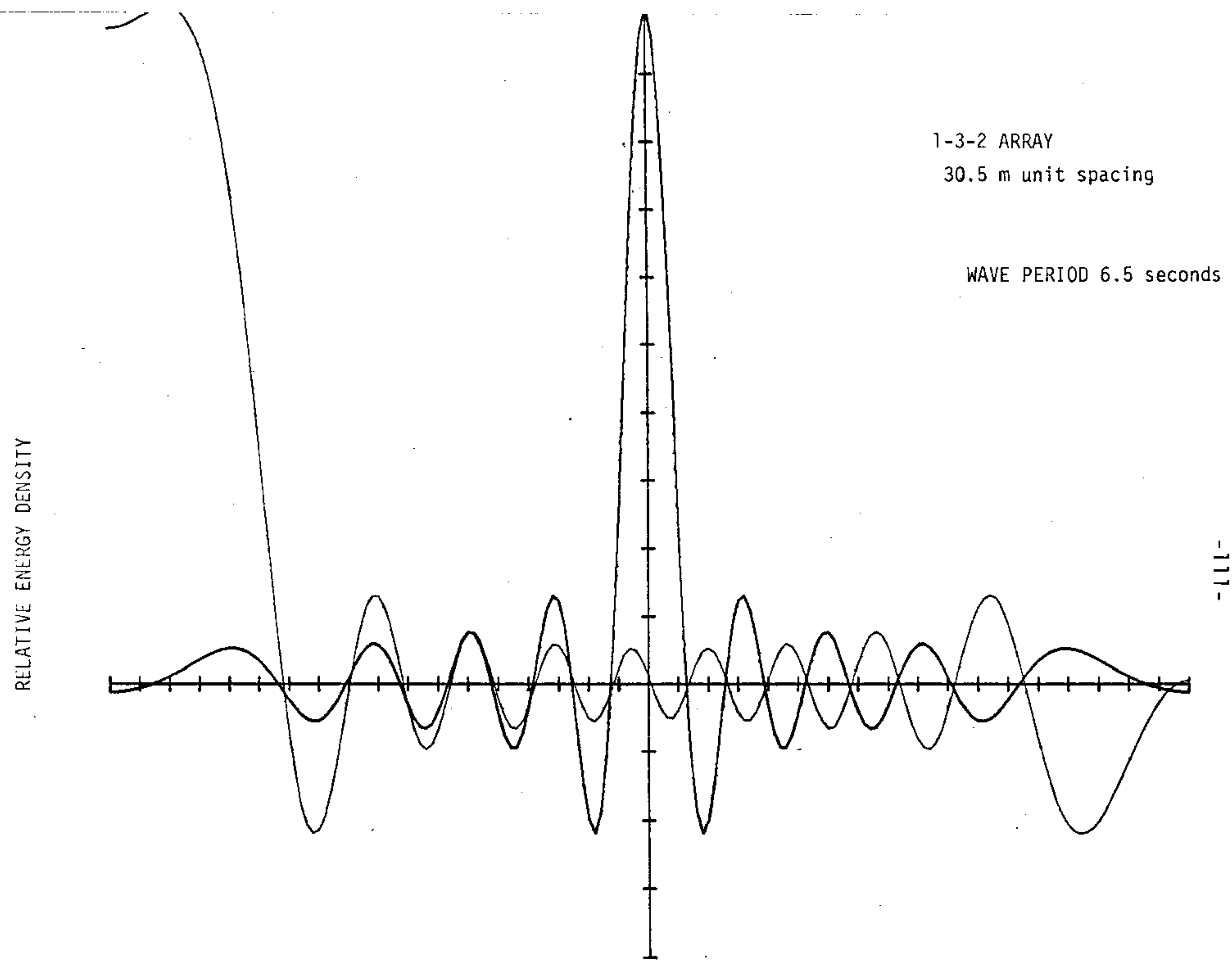


Figure 6. Beam pattern for 6.5 second waves for normal incidence and 80 degrees from normal incidence. The array has poor resolution for the waves with grazing incidence.

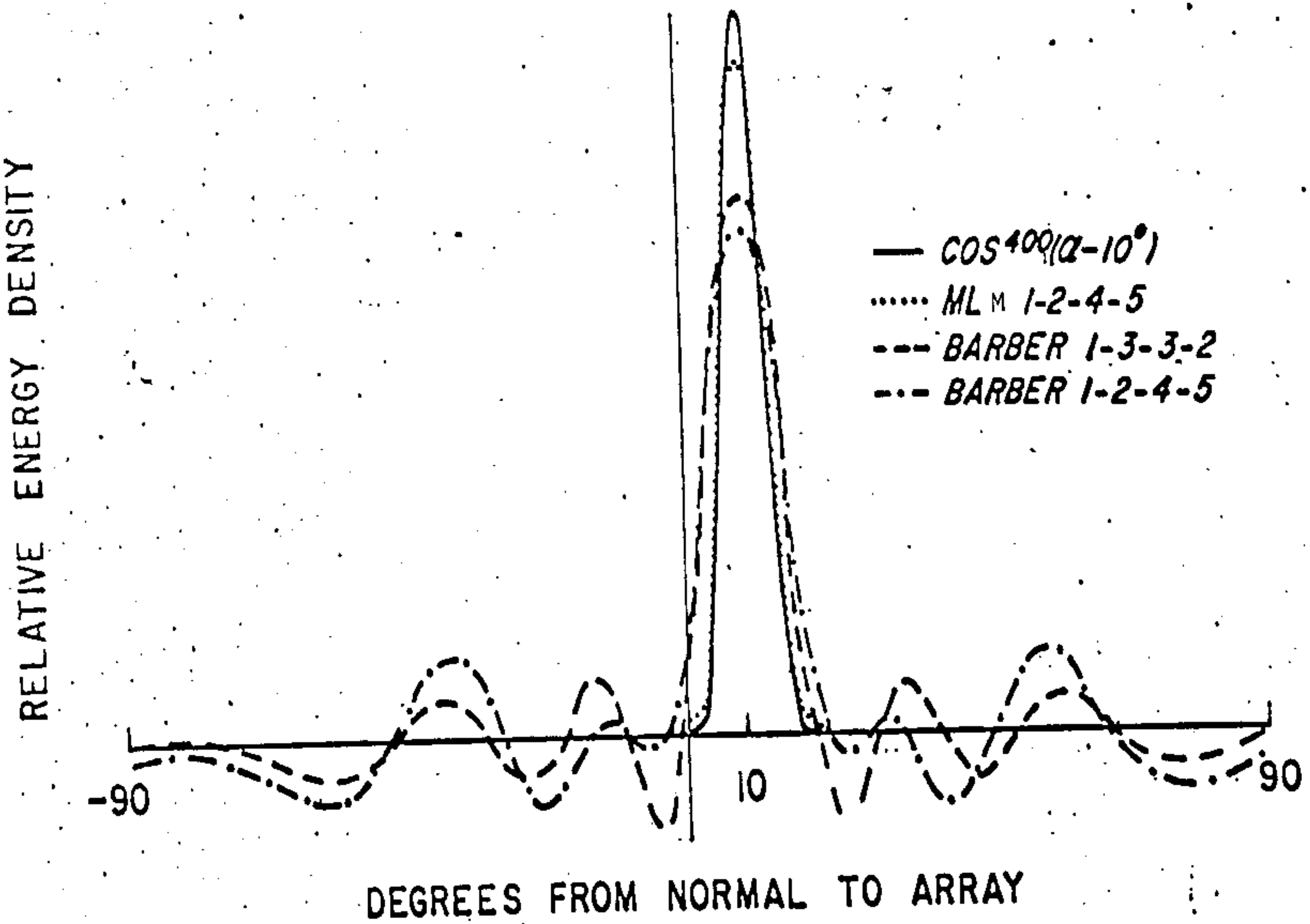


Figure 7. The directional spectrum estimates for two different methods; the Barber estimator (equal weighting of the lag information) and the maximum likelihood method.

REMOTE SENSING OF OCEAN WAVES IN NEARSHORE AREAS

by

O. H. SHEMDIN [1]

ABSTRACT

This paper presents a summary of remote sensing techniques for measuring waves. Photometric and radar methods are discussed. The principles of operation of the different sensors are briefly outlined and the accuracies of measurements are delineated. It is found that several viable remote sensing methods can be used for nearshore studies. The optimum techniques and platforms of deployment depend on location, scope, and nature of investigations contemplated.

Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Drive,
Pasadena, California 91103

INTRODUCTION

Remote sensing offers high technology and low labor methods for measuring ocean wave parameters from outside the hostile environment. In recent years, remote sensors mounted on aircraft and satellites have been shown to demonstrate capabilities for measuring wave height, length and direction, wind speed and direction, water surface temperature, and surface elevation, over relatively large areas of the ocean. These sensors are classified into visible, infrared, passive microwave, and active microwave systems seperated by wave length or frequency bands. Sensors operated at specified frequencies or wave lengths exhibit preferential sensitivity to certain oceanographic observables and/or surface dynamical properties. Multispectral color scanners, for example, detect ocean color and presence of ocean contaminents. Infrared and passive microwave sensors detect ocean surface temperature and wind speed. Active microwave systems provide all weather, day and night, capability for measuring wind speed and direction, and ocean wave properties.

The scope of this paper is confined to discussions of methods which provide information on surface waves in the nearshore environment.

REMOTE SENSING TECHNIQUES FOR OCEAN WAVE MEASUREMENTS

1. Photometric Methods (Visible Range)

Cox and Munk (1954 a, b) outlined a procedure for obtaining measurements of sea surface roughness from photographs of the Sun's glitter. Their proposed procedure derives statistical properties of the wave field from the upwind-downwind and crosswind properties of the glitter pattern. More recetly, Stilwell (1969), Stilwell and Pilon (1974) and Kasevich (1975) advanced optical procedures for obtaining the two-dimensional wave number spectrum from photographs of the sea surface. The photometrically derived spectra are especially useful in the high wave number range (wave lengths ≤ 5 cm) where surface penetrating wave gages loose response in detecting surface displacement. The latter is attributed to the time required for water to drain down the cylindrical probe surface; response characteristics of capacitance wave gages are discussed by Sturm and Sorrell (1973).

The difficulties associated with the photometric techniques stem from dependence on the ambient (sky) light distribution, sun angle, availability of sunlight, and nonlinearities in the relationship between illumination intensity and water surface slope; these factors are offset by the simplicity and availability of hardware, and operation of equipment. The photometric method can provide an accurate measurement of the dominant wave direction when the sea waves are visible.

2. Continuous Wave (CW) Doppler Radar

A CW-radar is a relatively simple radar which measures the intensity of ocean waves with wave number, κ. The latter is related to the radar wave number, κ_0, by the relationship

$$\kappa = 2\,\kappa_0 \cos\theta, \tag{1}$$

where θ is the depression view angle of antenna from the horizontal. The coherent coupling of radar transmitted signal with ocean surface waves at the specified wave number is referred to as Bragg scattering. Wright and Keller (1971) investigated the use of a CW radar in laboratory studies and verified that Bragg scattering is the dominant first order scattering mechanism for depression angles in the range of 20° to 70°. It is noted that for every depression angle and every radar frequency the intensity of one spectral component of a random ocean surface is detected. The total spectrum can only be obtained by varying the depression angle with a multi-frequency radar system. It is also noted that a CW doppler radar detects only the wave component along the line of sight of the radar antenna view angle. Nevertheless, in the laboratory study noted above the authors found excellent agreement between the short wave slope spectrum measured photometrically and that measured by the CW radar. The comparison was made in the wave number range 1 - 10 cm^{-1} (wave lengths 0.6 - 6.0 cm).

The backscattered radar cross section, σ_o, at the Bragg wave number, κ, is related to the wave height spectral value, $\Psi(\kappa)$, at the same wave number by the relationship

$$\sigma_o = \pi F(\theta) \kappa^4 \Psi(\kappa) , \tag{2}$$

where σ_o is a dimensionless value derived by dividing the backscattered power by the area illuminated by the radar beam, $F(\theta)$ represents the directional dependence of radar power return on depression angle, and $\pi = 3.14$.

In addition to measuring the Bragg wave intensities a CW doppler radar can measure the wave phase speed. The energy peak corresponding to the Bragg wave is found to have a doppler shift, f_d, which is related to the wave phase speed, c, by the following relationship

$$f_d = \frac{c}{\lambda} 2 \cos \theta , \tag{3}$$

where λ is the radar wave length ($= 2\pi/\kappa_o$). Conversely, the phase speed is directly measured by the doppler frequency for a given radar frequency and a known depression angle

$$c = \frac{f_d \lambda}{2 \cos \theta} . \tag{4}$$

When Bragg waves are modulated by long ocean waves their phase speeds oscillate as they propagate over the local current induced by the orbital velocity of the long waves. The corresponding oscillation in doppler frequency was recently correlated to the orbital velocity of the long waves as deduced from the in situ wave height measurements from a capacitance gage. The results, as reported by Plant, Keller and Wright (1977), are shown in Figure 1. The high degree of correlation lends credibility to the possibility of use of a CW doppler radar as a remote wave staff.

3. Pulsed Wave Scanning Radar

A scanning pulsed X-band radar is used to map the variation of the electromagnetic power return over the ocean surface it scans. The variation in the radial direction from the point of measurement is obtained by time delay techniques. The antenna rotates in a circular pattern to allow tangential detection of intensity variation. A typical imag of waves approaching shore, detected by a shore mounted radar, is shown in Figure 2. A radar of this type is operated by the Coastal Engineering Research Center. The images provide wave length and direction of dominant wave systems at different ranges from shore. Time lapse photography provides the wave speed. No obvious procedure is available at present for extracting wave height information from this radar. The radar imaging properties were carefully documented during the West Coast Experiment. The analysis of results is in progress.

4. HF Doppler Radar Techniques

Directional distribution of ocean waves at a fixed HF frequency, determined by the radar transmitter frequency, can be obtained by a synthesized aperture technique in which the transmitter is fixed and the receiver is moved along a path with a vehicle. Teague, Tyler, and Stewart (1977) describe the first order Bragg scattering results obtained by this technique in the experiment conducted at Wake Island. They verify their concepts by comparison with directional spectra obtained with a pitch and roll buoy. The transmitter used in their study had a frequency of 1.95 MHz which corresponds to 7 s period for ocean waves.

In the more recent West Coast Experiment the HF technique was used to determine the sheltering effect of islands in the Southern California Bight. The distribution of 7 s waves were measured at various approach angles to the receiver which was placed at San Clemente. A sample contour map of the energy distribution propagating towards the receiver is shown in Figure 3. High wave energy levels are seen to penetrate the window defined as a wedge with its south boundary tangent to north of Santa Catalina Island and the north boundary tangent to south of Santa Rosa Island. A more modest energy level is seen to penetrate the window between north of St. Clemente Island and south of Santa Catalina Island. The incoming energy between the two windows is masked by Santa Catalina Island. The utility of HF radar for ocean wave studies is distinctly demonstrated in the West Coast Experiment. Detailed analysis of results is in progress.

The extraction of the complete directional ocean wave spectrum from HF radar is being investigated by Trizna, et al. (1977) and Barrick and Snider (1977). The second order features of the radar Doppler Spectrum are found to be related to the ocean directional wave height spectrum. The results to date appear encouraging as demonstrated by Lipa (1977).

5. Synthetic Aperture Radar (SAR)

This technique employs the use of airborne or spaceborne transmitter and receiver system which detects intensity variation of scatterers at known positions in range and azimuth on the ocean surface. The principle of radar imaging is shown in Figure 4 as given by Elachi and Brown (1977). By processing the signal received during flight (denoted as signal film) through an optical processor, it is possible to reconstruct the ocean surface terrain. The optical processing of SAR data is described in detail by Jordan and Bicknell (1976). Models of radar imaging mechanisms of ocean surface waves were discussed by Elachi and Brown (1977) in preliminary form. Intensive research on this subject is in progress. A typical SAR image of waves in hurricane Gloria II obtained by the JPL: L-band system is shown in Figure 5.

The synthetic aperture radar provides all weather capability for obtaining ocean wave images during day or night hours. Wave direction of dominant waves can be determined to within a few degrees (2° - 5°). These images do not provide information on wave heights. The latter must be supplemented with other wave height measuring sensors. Preliminary results on comparison between radar derived and in situ measured ocean wave spectra were given by Shemdin, et al. (1977).

The SEASAT-A synthetic aperture radar has a resolution of 25 m. An equivalent aircraft system produced excellent images of waves in hurricanes during summer 1976. Dominant waves of 100 - 250 m were detected in various directional patterns.

6. Real Aperture Radar

This radar is an airborne imaging system which is operated in much the same way as the synthetic aperture radar except that the doppler information (or phase history) is not recorded. The variation in backscattered intensity over an ocean wave field is imaged directly to yield the ocean surface terrain. This technique requires a less complex hardware system and can provide discernable ocean wave images. The system is not suitable for use in high flying aircraft or spacecraft. The intensity of backscattered energy is inversely proportional to the distance between the platform and the ocean surface. The power requirements become excessive for high altitude platforms.

7. Radar Altimeter (ALT)

The radar altimeter transmits a pulsed signal from a high flying stable platform and monitors the time of travel of the transmitted and backscattered pulse from the ocean surface. The time of travel is then used to determine the distance between the platform and the ocean surface. For a known satellite orbit the variation in ocean surface elevation can be determined from the change in the time of travel of the transmitted and backscattered pulse. The SEASAT-A altimeter has a resolution of 10 cm for detecting ocean surface elevation. The beam width is 1.5° giving a spot size 1.6 - 12.0 km on the ocean surface.

For a square transmitted pulse the backscattered pulse is distorted by interaction with a random ocean surface. The shape of the return signal determines the position of the mean surface and the properties of the scattering ocean surface. Figure 6 defines the geometry of a short pulsed satellite altimeter as presented by Barrick (1972). For a pulse-limited altimeter, normally encountered with satellite geometries, Barrick found the rise shape of the return signal, σ, to be an error function as follows

$$\sigma(t) = \frac{\pi \ell \tau}{2\ s^2 \left[(1/a) + (1/H)\right]} \ \mathrm{erf}\left(\frac{\ell t}{\sqrt{8}\ h}\right) , \tag{5}$$

where τ is the radar pulse widths, a and H are as defined in Figure 6, h is rms wave height, s is rms wave slope, ℓ is speed of light, and t is time. The maximum return signal, σ_{max}, was also found to be

$$\sigma_{max} = \frac{\pi \ell \tau}{s^2 \left[(1/a) + (1/H)\right]} \quad . \tag{6}$$

The slope of the rise signal is shown graphically in Figure 7 for seas with different significant wave heights. The SEASAT-A altimeter is designed to measure significant wave heights in the range 1 - 20 m with errors of 50 cm or 10% of actual significant wave height.

For nearshore studies the radar altimeter can provide the significant wave height and storm surge elevation along tracks normal to shore or parallel to shore to relate offshore to nearshore conditions and/or to measure alongshore variations, respectively.

8. Dual-Frequency Radars

Dual-frequency radar techniques have been demonstrated to measure wave height statistics [Weissman and Johnson (1977)] and to measure spectral properties [Plant (1977)]. The first system denoted by Dual-Frequency Scatterometer, was tested with aircraft in the nadir looking mode. The width of the cross correlation vs. Δf function was found to be inversely proportional to the significant wave height, where Δf denotes the difference in the two transmitted frequencies. The single frequency scatterometer provides a measure of the wind speed. The dual-frequency version adds the capability for measuring the significant wave height.

In a seperate study conducted from a cliff adjacent to shore Plant (1977) investigated radar look angles away from nadir. The dual-frequency system was found to produce first order Bragg scattering from ocean waves corresponding to the beat frequency of the dual-frequency radar system. The system was found capable of measuring the phase speed of long waves and the shape of the spectrum in much the way as the single frequency system measures the properties of short waves (discussed in previous section). The technique offers a unique capability for measuring the long ocean wave spectrum in the direction of antenna view angle.

SUMMARY AND CONCLUSIONS

A review is made of remote sensing techniques for measuring waves in nearshore areas. The principles of operation are discussed and samples of the various types of measurements obtained and their accuracies are presented. The instruments are operated from different platforms ranging from surface to aircraft and satellite. A comparison is summarized in Table 1. Various combinations of sensors can be selected depending on the nature of a nearshore investigation and the scope and location of effort contemplated. Typically, for surface zone studies shore based radars offer optimum use and economy. For shelf type studies, primarily aircraft and satellites-borne instruments offer the needed measurement capability. In remote nearshore areas such as in the southern hemisphere only satellite instruments offer economic means for measuring waves.

The development of radar techniques for ocean wave studies is recent as can be inferred from the dates of attached references. The concepts will gain in recognition among users as the merits of radar are demonstrated in scientific and engineering studies involving ocean waves. Vigorous research and development is in progress on radar technology for ocean studies. It is anticipated that future studies of the ocean will be dominated by radar techniques.

Table 1. Summary of Remote Sensors Capabilities

	Significant Wave Height	Directional Spectrum	All Weather Day/Night	Dominant Wave Direction	Platform
Photometric	X	X	----	X	A, G
CW Doppler single frequency	X	----	X	----	G
PW Scanning radar	----	----	X	X	G
HF -Doppler radar	X (research in progress)	X (research in progress)	X	only specific periods	G
Synthetic Aperture Radar	----	----	X	X	A, S
Real Aperture Radar	----	----	X	X	A
Radar Altimeter	X	----	X	----	A, S
Dual Frequency Radar-Bragg	X	X	X	X	G
Dual Frequency - Nadir Viewing	X	----	X	----	A

A - Aircraft

G - Ground

S - Satellite

REFERENCES

Barrick, D. E. (1972), "Determination of Mean Surface Position and Sea State from the Radar Return of a Short-Pulse Satellite Altimeter," NOAA Tech. Report ERL 228-AOML 7, Boulder, Colorado.

Barrick, D. E. and Snider, J. B. (1977), "The Statistics of HF Sea-Echo Doppler Spectra, IEEE Transactions on Antennas and Propagation, AP-25, 19 - 28.

Cox, C. S. and Munk, W. H. (1954 a), "Statistics of the Sea Surface Derived from Sun Glitter," J. Mar. Res., 13, 198 - 227.

Cox, C, S, and Munk, W. H. (1954 b), "Measurements of the Roughness of the Sea Surface from Photographs of the Sun's Glitter," J. Optical Soc. Amer., 44, 838 - 850.

Elachi, C. and Brown, Jr., W. E. (1977), "Models of Radar Imaging of the Ocean Surface Waves," IEEE Transactions on Antennas and Propagation, AP-25, 84 - 95.

Jordan, R., and Bicknell, T. (1976), "Data Processing for a Synthetic Aperture Radar from an Earth-Orbiting Spacecraft," JPL Tech. Report No. 622-8, Pasadena, California.

Kasevich, R. S. (1975), "Directional Wave Spectra from Daylight Scattering," J. Geophys. Res., 80, 4535 - 4541.

Lipa, B. (1977), "Integral Inversion of Second Order Radar Echoes to Give Directional Ocean-Wave Spectra," J. Bound. Layer Meteo., in press.

Plant, W. J. (1977), "Studies of Backscattered Sea Return with a CW, Dual-Frequency, X-band Radar," IEEE Transactions on Antennas and Propagation, AP-25, 28 - 36.

Plant, W. J., Keller, W. C., and Wright, J. W. (1977), "Modulation of Coherent Microwave Backscatter by Shoaling Waves," Private Communications.

Shemdin, O. H., Brown, W. E., Staudhammer, F. G., Shuchman, R., Rawson, R., Zalenka, J., Ross, D. B., McLeish, W., and Berles, R. A. (1977), "Comparison of In Situ and Remotely Sensed Ocean Waves off Marineland, Florida," J. Bound. Layer Meteo., in press.

Stilwell, D., Jr. (1969), "Directional Energy Spectra of the Sea from Photgraphs," J. Geophys. Res., 74(8), 1974 - 1986.

Stilwell, D., Jr., and Pilon, R. O. (1974), "Directional Spectra of Surface Waves from Photographs," J. Geophys. Res., 79(9), 1277 - 1284.

Sturm, G. V. and Sorrell, F. Y. (1973), "Optical Wave Measurement Technique and Exprimental Comparison with Conventional Wave Height Probes," Appl. Optics, 12(8), 1928 - 1933.

Teague, C. C., Tyler, G. L., and Stewart, R. H. (1977), "Studies of the Sea Using HF Radio Scatter," IEEE Transactions on Antennas and Propagation, AP-25, 19 - 28.

Trizna, D. B., Moore, J. C., Headrick, J. M., and Bogle, R. W. (1977), "Directional Sea Spectrum Determination Using HF Doppler Radar Techniques," IEEE Transactions on Antennas and Propagation, AP-25, 1 - 4.

Weissman, D. E. and Johnson, J. W. (1977), "Dual Frequency Correlation Radar Measurements of the Height Statistics of Ocean Waves," IEEE Transactions on Antennas and Propagation, AP-25, 74 - 84.

Wright, J. W., and Keller, W. C. (1971), "Doppler Spectra in Microwave Scattering from Wind Waves," Phys. Fluids, 14, 466 - 474.

LIST OF FIGURES

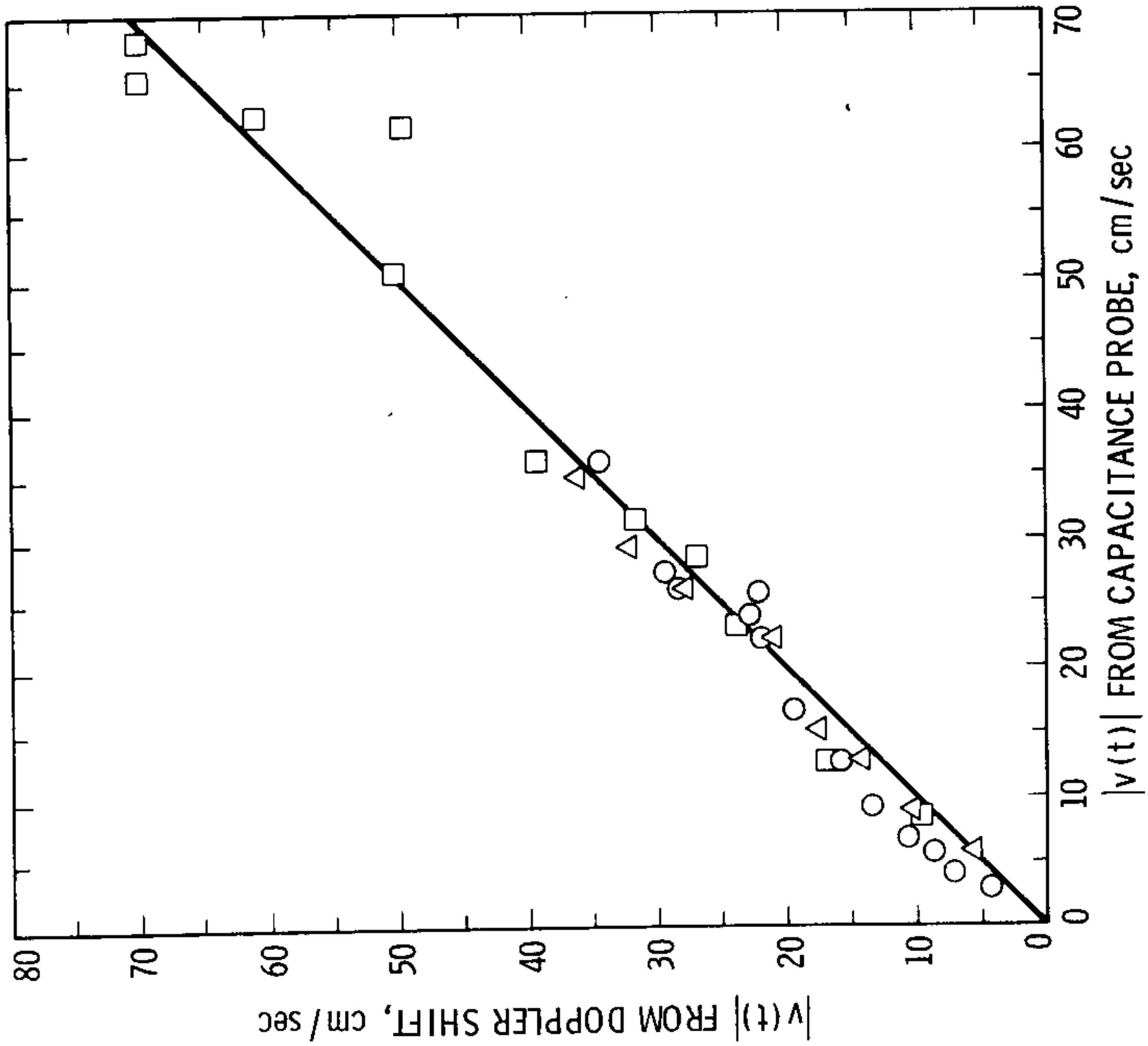

|v(t)| FROM CAPACITANCE PROBE, cm/sec
|v(t)| FROM DOPPLER SHIFT, cm/sec
0
10
20
30
40
50
60
70
80

Figure 1

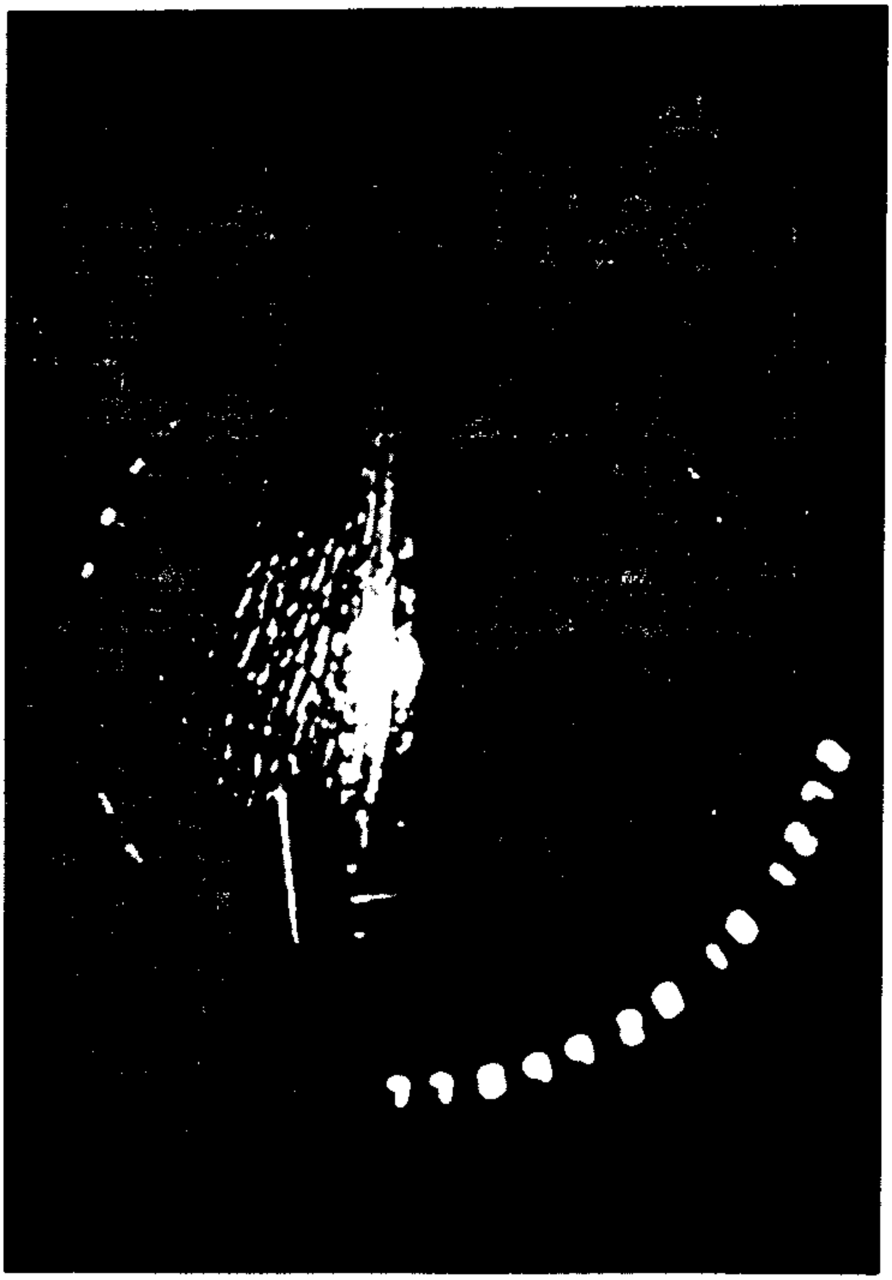
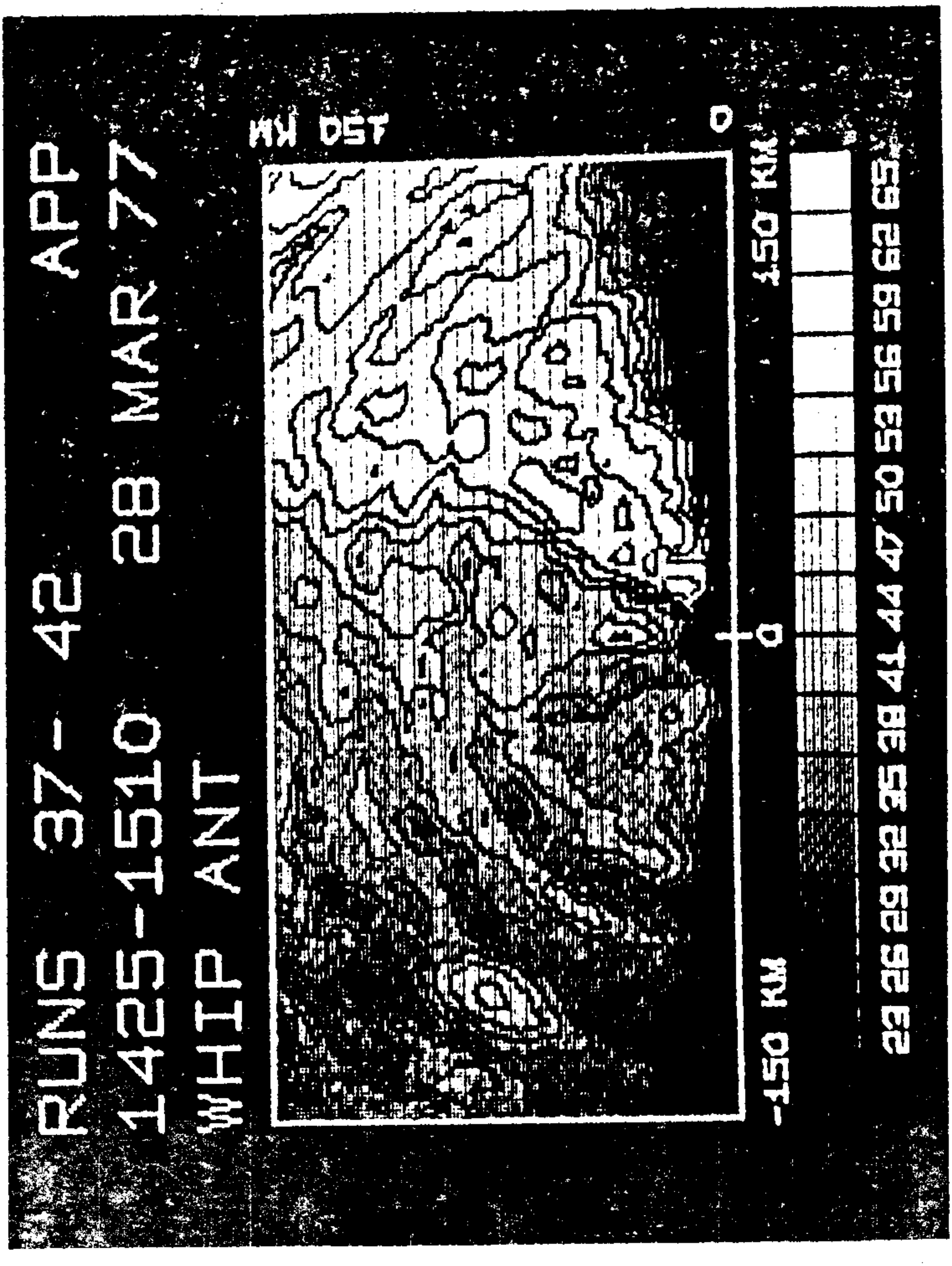
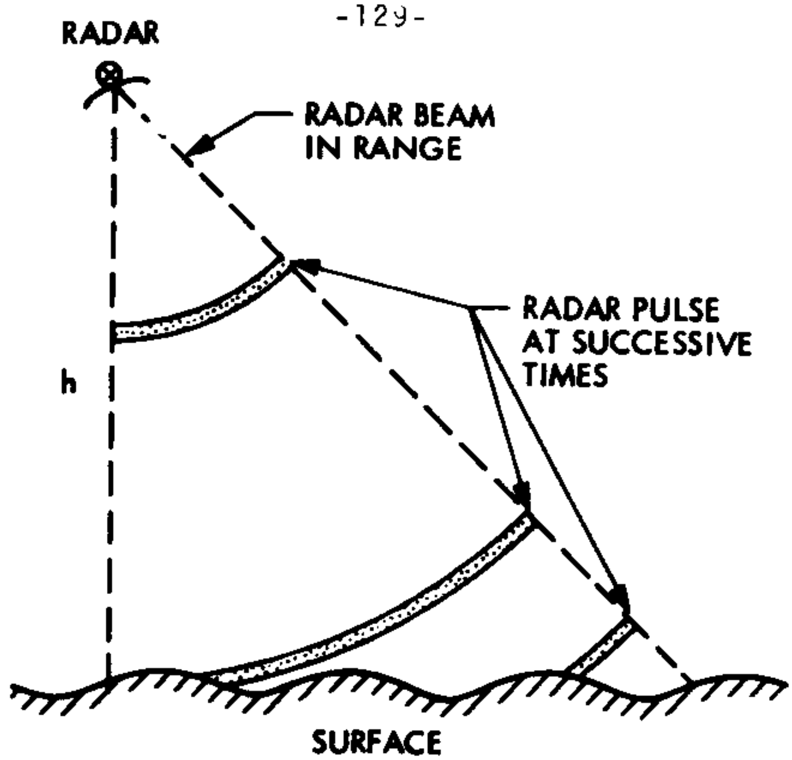


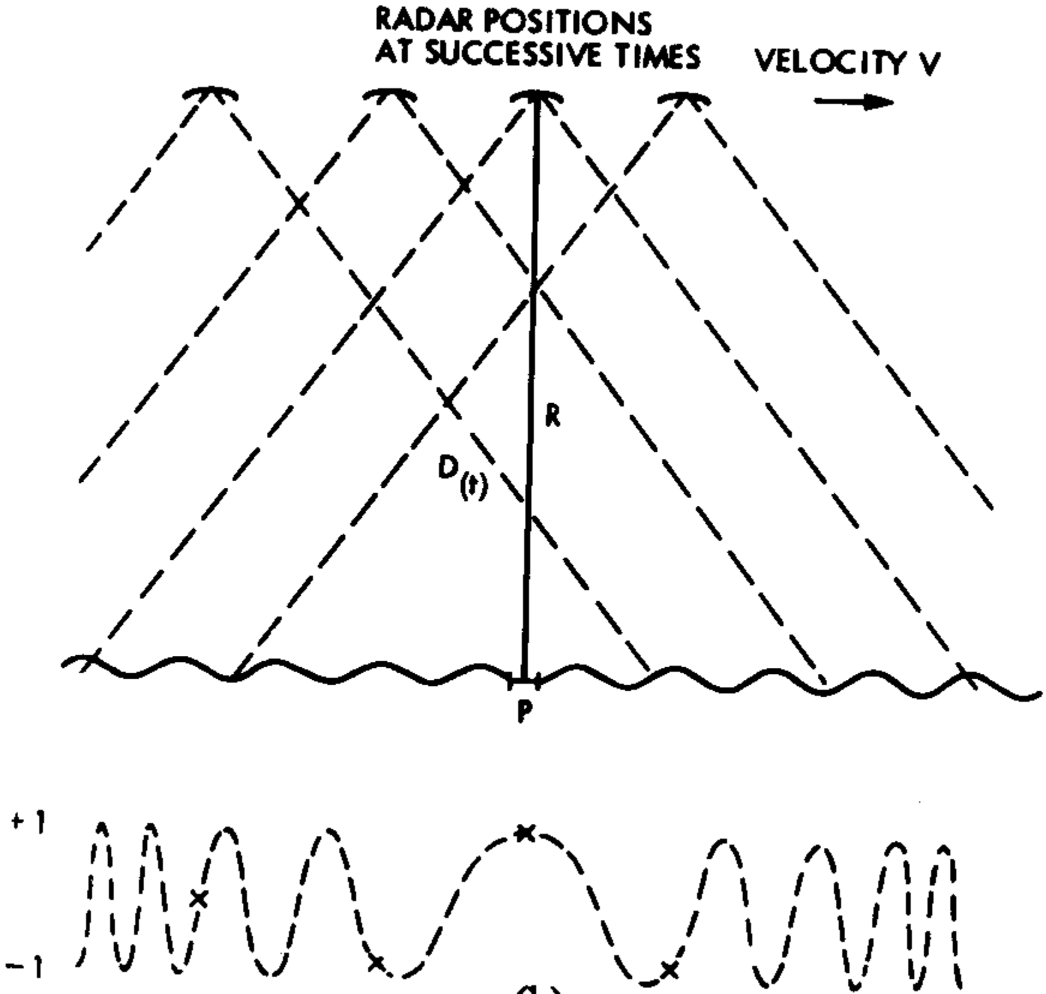
Figure 2


RUNS 37- 42 APP
1425-1510 28 MAR 77
WHIP ANT
150 KM
0
-150 KM
0
150 KM
23 26 29 32 35 38 41 44 47 50 53 56 59 62 65

Figure

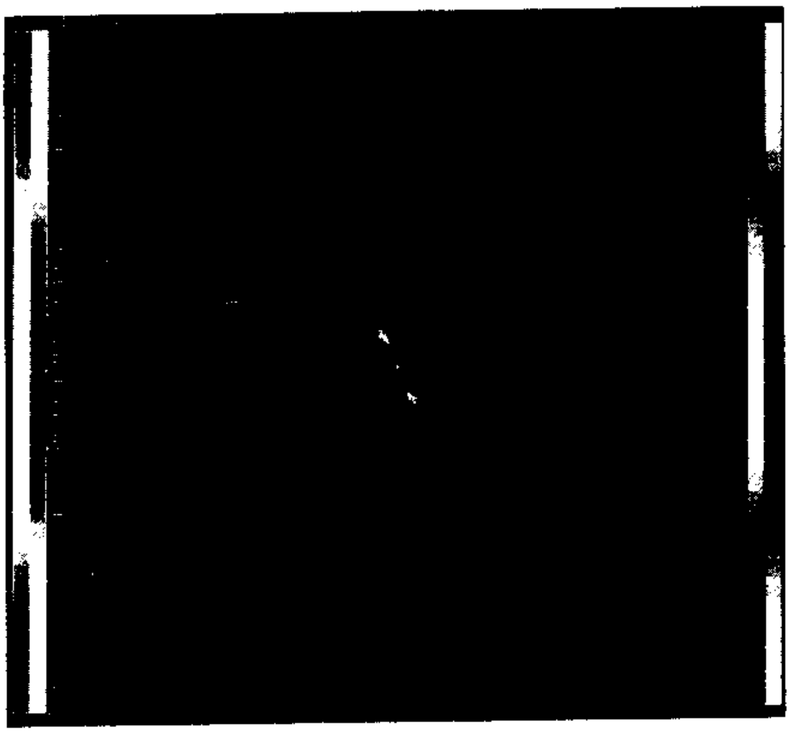

RADAR
RADAR BEAM IN RANGE
RADAR PULSE AT SUCCESSIVE TIMES
h
SURFACE

(a)

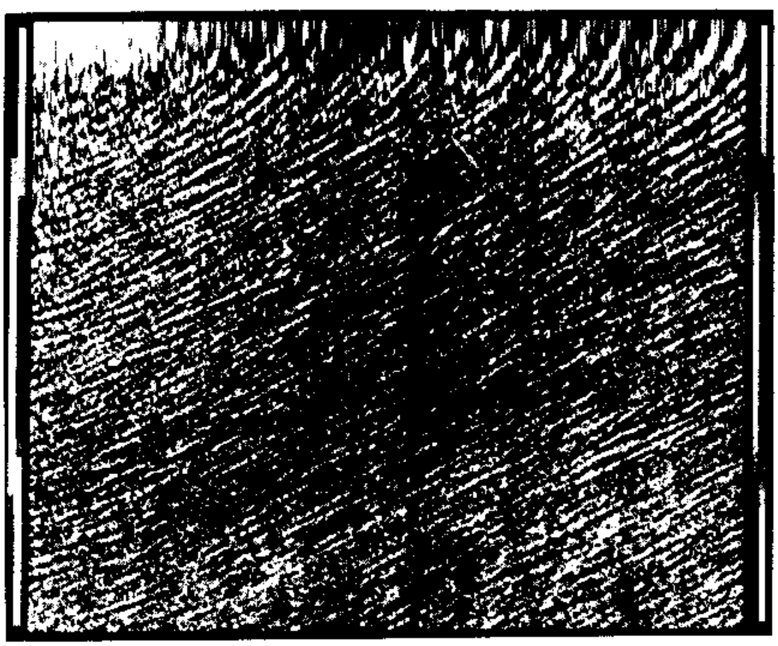

RADAR POSITIONS AT SUCCESSIVE TIMES
VELOCITY V
R
D(t)
P
+1
-1

(b)

Figure 4



(b)



(a)

Figure 5

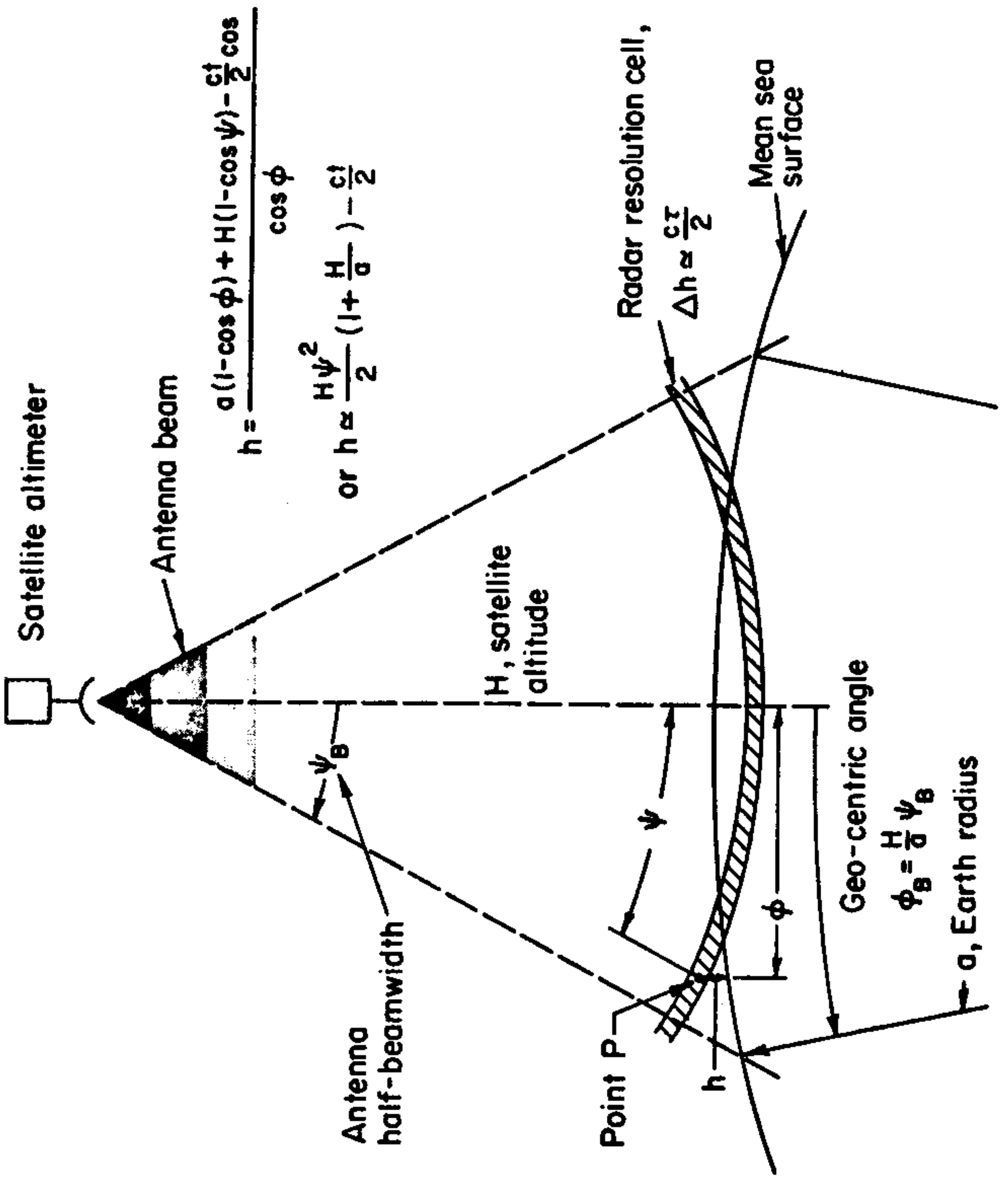

Satellite altimeter
Antenna beam
$h = \frac{a(1-\cos\phi) + H(1-\cos\psi) - \frac{ct}{2}\cos}{\cos\phi}$
or $h \simeq \frac{H\psi^2}{2}(1+\frac{H}{a}) - \frac{ct}{2}$
H, satellite altitude
Radar resolution cell,
$\Delta h \simeq \frac{c\tau}{2}$
Mean sea surface
ψ_B
ψ
ϕ
Geo-centric angle
$\phi_B = \frac{H}{a}\psi_B$
a, Earth radius
Antenna half-beamwidth
Point P
h

Figure 6

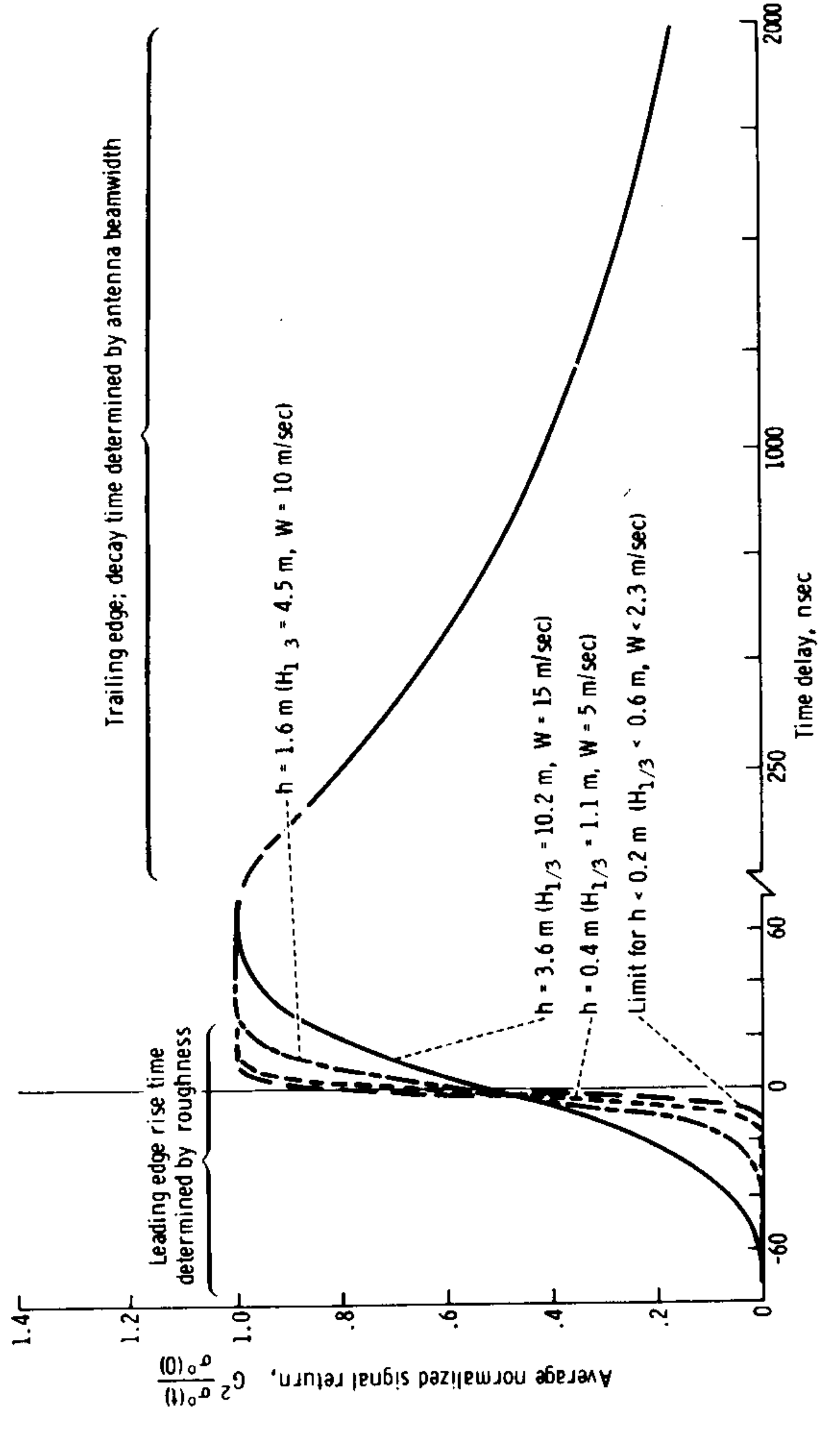

Trailing edge; decay time determined by antenna beamwidth
Leading edge rise time determined by roughness
h = 1.6 m ($H_{1/3}$ = 4.5 m, W = 10 m/sec)
h = 3.6 m ($H_{1/3}$ = 10.2 m, W = 15 m/sec)
h = 0.4 m ($H_{1/3}$ = 1.1 m, W = 5 m/sec)
Limit for h < 0.2 m ($H_{1/3}$ < 0.6 m, W < 2.3 m/sec)
Time delay, nsec
-60
0
60
250
1000
2000
Average normalized signal return, $G^2 \frac{\sigma^\circ(t)}{\sigma^\circ(0)}$
0
.2
.4
.6
.8
1.0
1.2
1.4

Figure 7

A SLOPE ARRAY FOR ESTIMATING WAVE DIRECTION

Richard J. Seymour
California Department of Navigation
and Ocean Development

Alan L. Higgins
Scripps Institution of Oceanography

INTRODUCTION

The concept of measuring wave directional properties from a knowledge of the time history of sea surface slope is well known. Longuet-Higgins, Cartwright and Smith (1963) and Misuyasu, et al., (1975) report on deep water investigations using a surface following buoy. In shallow water, a fixed array of gages offers some operational advantages over moored buoys. The California Coastal Engineering Data Network project, jointly sponsored by the Department of Navigation and Ocean Development, and the Sea Grant Program, has undertaken investigations of the feasibility of employing small arrays of bottom-mounted pressure transducers to estimate wave direction just outside the surf zone to provide data for predicting longshore transport of sediment.

THEORY

Longuet-Higgins, et al., (1963) shows that the time series

$$\eta(t),\ \frac{\partial\eta}{\partial x}(t),\ \text{and}\ \frac{\partial\eta}{\partial y}(t)$$

may be used to obtain estimates of the first five Fourier coefficients of the directional spectrum $E(f,\theta)$

$$a_n + ib_n = \frac{1}{\pi}\int_0^{2\pi} e^{ni\theta}\ E(f,\theta)\ d\theta \tag{1}$$

One of these coefficients, $C_{\eta_x\eta_y}$, is the cospectrum of η_x and η_y.

$$C_{\eta_x\eta_y}(f) = \int_0^{2\pi} K^2\cos\theta\sin\theta\ E(f,\theta)d\theta \tag{2}$$

where K = wave number

For any frequency band, i, $(S_{xy})_i$, the longshore component of shoreward directed momentum flux is given by

$$(S_{xy})_i = n_i \sum_{\theta=-\frac{\pi}{2}}^{\frac{\pi}{2}} E(\theta,i) \cos\theta\sin\theta \qquad (3)$$

$$\text{Therefore, } (S_{xy})_i = \frac{n_i}{K_i^2} (C\eta_x\eta_y)_i \qquad (4)$$

Thus, if (S_{xy}) and $(E_{total})_i$ can be estimated, then an apparent wave angle, $\hat{\theta}$, can be calculated such that

$$(S_{xy})_i = (E_{total})_i \; n_i \cos\hat{\theta}\sin\hat{\theta} \qquad (5)$$

It can be seen from equation 5 that the apparent angle, $\hat{\theta}$, is an estimate of the one approach angle that would result in the same longshore component of momentum flux within that frequency band as the sum of the contributions from all approach angles in the real wave field. Thus, as opposed to concepts like significant angle, average angle, etc., $\hat{\theta}$ is an estimate of a precisely defined quantity and it can be readily compared to estimates obtained from other means of measuring wave directional characteristics (i.e., directional spectra).

METHOD OF ANALYSIS

Three bottom-mounted pressure transducers are arranged at the corners of a right triangle such that they form one gage pair parallel to the contours of constant depth and a second gage pair perpendicular to the first. A constant surface slope is assumed between each pair of transducers.

$$\eta_x = \frac{\eta_1 - \eta_2}{L_x} \qquad (6)$$

$$\eta_y = \frac{\eta_3 - \eta_2}{L_y} \qquad (7)$$

η_x is the slope in the offshore direction, η_y is the slope in the longshore direction and L_x and L_y are the offshore and longshore gage lengths, respectively.

The Fourier transforms are calculated for the time series of pressure from each transducer and the standard correction from linear wave theory is applied to obtain the transforms of surface elevation at each point. From the linearity of Fourier transforms and equations 6 and 7, the transforms of the slope components can be obtained:

$$F_{\eta_x} = (F_{\eta_1} - F_{\eta_2})\, L_x^{-1} \tag{8}$$

$$F_{\eta_y} = (F_{\eta_3} - F_{\eta_2})\, L_y^{-1} \tag{9}$$

Sufficient smoothing is performed on periodograms obtained from these transforms to estimate $\chi_{\eta_x\eta_y}(f)$, the cross spectrum of η_x and η_y.

Substituting

$$C_{\eta_x\eta_y}(f) = \mathrm{Re}\left\{\chi_{\eta_x\eta_y}(f)\right\} \tag{10}$$

into equation 4 and combining with equation 5 yields

$$\sin\hat{\theta}\cos\hat{\theta} = \frac{\mathrm{Re}\left\{\chi_{\eta_x\eta_y}(f)\right\}}{E_{(f)}\ K^2} \tag{11}$$

and

$$\hat{\theta} = \frac{1}{2}\sin^{-1}\left[\frac{2\ \mathrm{Re}\left\{\chi_{\eta_x\eta_y}(f)\right\}}{K^2\ E(f)}\right] \tag{12}$$

ERROR ANALYSIS

Two sources of errors can be identified for this method. The first is the error in measuring pressure caused by the instrument and data system resolution and noise from various sources. This is assumed to be a broadband random error. The effect in the frequency domain of slope measurement error is of the form

$$\varepsilon = \frac{2\sigma \cosh(Kh)}{L} \tag{13}$$

where h = water depth
and σ = standard deviation of measurement error

The second source of error arises from approximating the slope of a sinusoidal component by measurements at three finitely separated points. The effect of this error on the estimation of a slope component can be shown to be

$$\varepsilon_j = \eta_j \left[1 - \frac{\sin\left(\frac{KL_j}{2} M\right)}{\left(\frac{KL_j}{2} M\right)} \right] \tag{14}$$

$$\text{where } M = \begin{cases} \cos\theta, & j = x \\ \sin\theta, & j = y \end{cases}$$

Thus the combined errors for the estimation of slope components are

$$\varepsilon_x = \eta_x \left[1 - \frac{\sin\left(\frac{KL_x}{2} \cos\theta\right)}{\left(\frac{KL_x}{2} \cos\theta\right)} \right] + \frac{2\ \sigma \cosh(Kh)}{L_x} \tag{15}$$

and

$$\varepsilon_y = \eta_y \left[1 - \frac{\sin\left(\frac{KL_y}{2} \sin\theta\right)}{\left(\frac{KL_y}{2} \sin\theta\right)} \right] + \frac{2\ \sigma \cosh(Kh)}{L_y} \tag{16}$$

The resulting error in estimating S_{xy} is the cospectrum of the offshore and longshore slope errors. To first order this is

$$\tilde{S}_{xy}(f) = \frac{n}{K^2}\left\{A_{n_x}(f)A_{n_y}(f)\left[2-\frac{\sin\left(\frac{KL_x}{2}\cos\theta\right)}{\left(\frac{KL_x}{2}\cos\theta\right)}\right.\right.$$

$$\left.\left.-\frac{\sin\left(\frac{KL_y}{2}\sin\theta\right)}{\left(\frac{KL_y}{2}\sin\theta\right)}\right] + 2\,\sigma\cosh(Kh)\left[\frac{A_{n_x}(f)}{L_y} + \frac{A_{n_y}(f)}{L_x}\right]\right\} \quad (17)$$

where A_{n_x} = amplitude spectrum of n_x

When a triangular array is used and one transducer is shared by both gage pairs, an additional bias error is introduced. Discussion of this crossproduct error is beyond the scope of this paper. However, the error may be eliminated completely if four transducers are used so that no transducer sharing is required.

ARRAY GEOMETRY AND GAGE LENGTH SELECTION

It can be seen from equation (17) that errors are a function of the wave climate to be measured as well as the gage lengths employed. Thus, the dimensions which would result in minimal error vary both with season and location.

Wave climate records of over one year in length exist at Scripps pier and several other locations as described in Seymour, et al. (1977). Four average seasonal frequency spectra of three months' length (fall, winter, spring, summer) were computed. Best gage lengths based on these wave climate averages were found to vary only slightly from one to another. This suggests that the choice of array dimensions by this method exhibits some stability with respect to the seasons.

For practical reasons, it may be desirable to use gage lengths which are shorter than the computed optimum, particularly in the longshore direction. The decision to do this should be made in the light of resulting errors.

System reliability may be increased by employing one redundant transducer in a four-gage rectangular array.

EXPERIMENTAL VERIFICATION

A subscale array was evaluated in the wind wave channel at the Hydraulics Laboratory at Scripps Institution of Oceanography. The gage lengths were 90 cm in both directions. A simulated random sea with a peak period of about four seconds was employed and the array was rotated through several angles relative to the center line of the wave channel to provide a number of approach directions. The pressure transducers used in this experiment were the Gulton differential transformer type as described in Seymour and Sessions (1976) and have an assumed standard deviation measurement error of one mm. It can be seen from equation 13 that scaling down the gage length for a laboratory experiment without scaling down the measurement error by the same ratio will result in an increase in the slope error proportional to the scale factor. Figure 1 shows the results of one of the runs with an approach angle of 20 deg. The agreement between predicted and measured S_{xy} is seen to be quite good over the portion of the spectrum where significant energy exists.

Figure 2 shows the angle estimation from the same experiment. The error in estimating the approach angle can be seen to be a maximum of a few degrees over the full range of interest. This is a particularly gratifying result since the measurement error scales unfavorably as noted above.

The large deviation in predicted angle at low frequencies, which occurs in a range where there is not a significant contribution to S_{xy}, may possibly be caused by reflection of these very long waves from the beach in the wave channel. Since the array cannot distinguish the 180 deg. direction ambiguity, reflected energy can bias the estimate of S_{xy} and, therefore, of the incidence angle.

Figure 3 shows the errors in predicting S_{xy} in this experiment compared to the prediction of the error given by equation (17). The agreement of the predicted and actual errors is very good in the area where S_{xy} is largest.

FIELD EVALUATION

A full-scale array with a 6 m gage length in both the offshore and the longshore directions has been installed at Torrey Pines Beach in conjunction with the five-gage linear array operated by the Shore Processes Laboratory and described in Pawka (1977). Data have been recorded concurrently with the slope and the linear array under a variety of wave climates and are presently being analyzed for comparison. The results will be reported in a future publication.

REFERENCES

1. Longuet-Higgins, M. S., Cartwright, D. E., and Smith, N. D., "Observations of the Directional Spectrum of Sea Waves Using the Motions of a Floating Buoy." Ocean Waves Spectra, Proceedings of a Conference, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1963.

2. Mitsuyasu, H., et al., "Observations of the Directional Spectrum of Ocean Waves Using a Cloverleaf Buoy," Journal of Physical Oceanography, Vol. 5, 1975, pp. 750-760.

3. Seymour, R. J., and Sessions, M. H., "A Regional Network for Coastal Engineering Data." Proc., Fifteenth Int. Conf. on Coastal Engineering, Honolulu, Hawaii, July 1976.

4. Seymour, R. J.; Sessions, M. H.; Wald, S. L.; and Woods, A. E.; "Coastal Engineering Data Network Second Semi-Annual Report, July 1976 to December 1976." Institute of Marine Resources, University of California, IMR Ref. 77-103. Sea Grant Pub. No. 56. January 1977.

5. Pawka, S. S., "Linear Arrays." Proceedings of a Workshop on Instrumentation for Nearshore Processes, La Jolla, California, June 1977.

COMPARISON OF PREDICTED
AND MEASURED S_{xy} FOR
LABORATORY EXPERIMENT WITH
20 DEG. INCIDENCE ANGLE
(84 DEGREES OF FREEDOM)

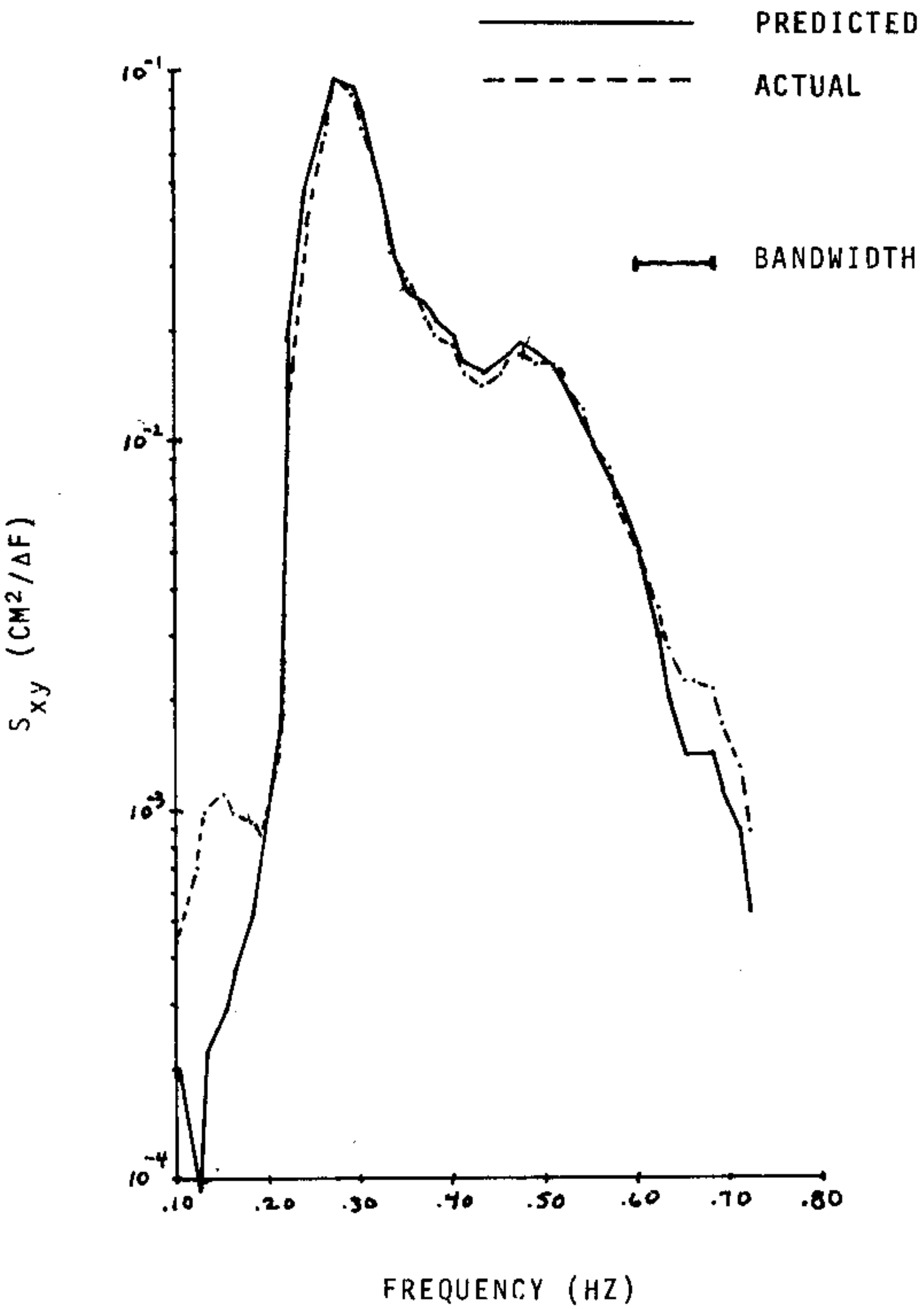
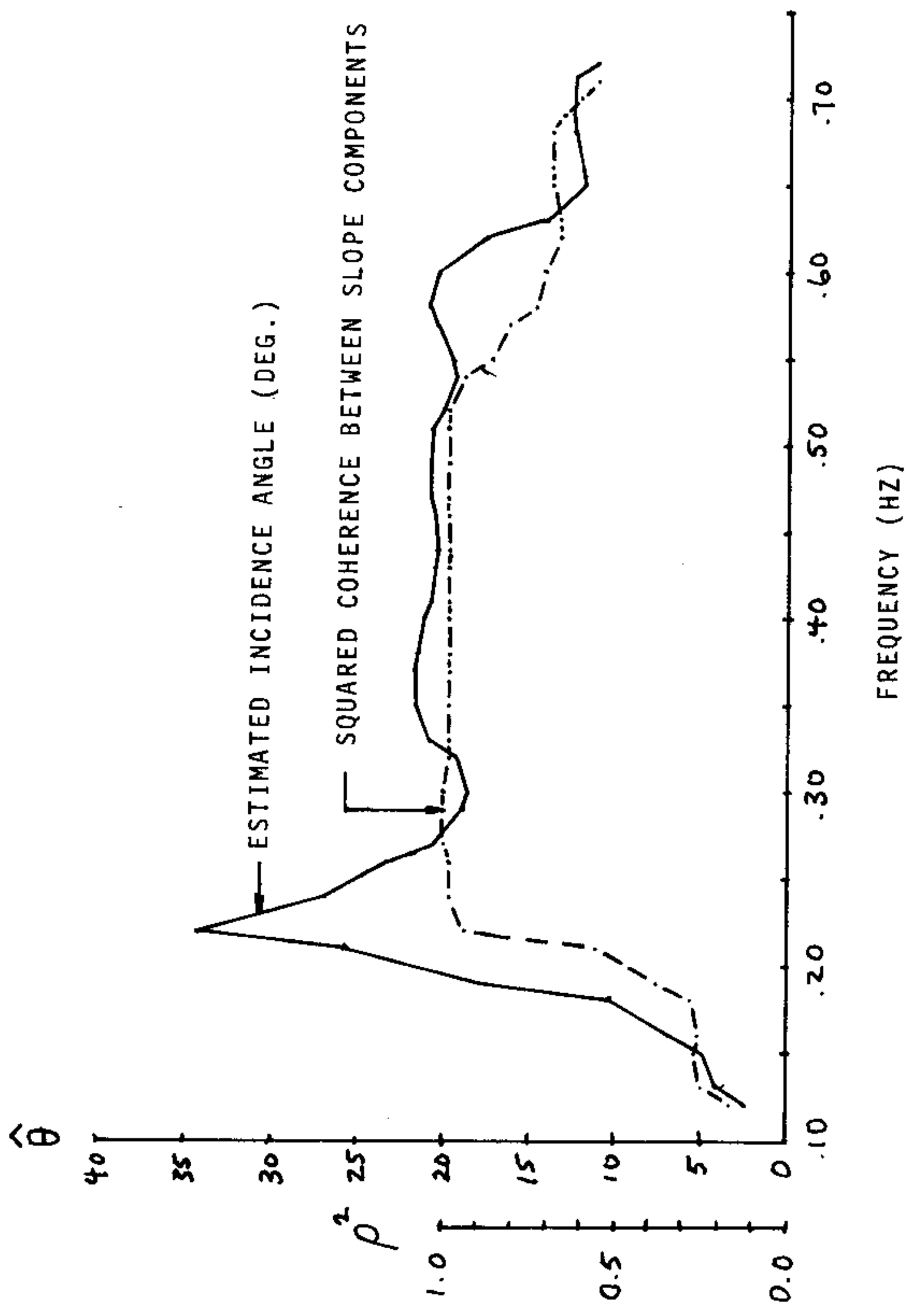


FIGURE 1



ESTIMATED INCIDENCE ANGLE (FOR MEASURED ANGLE OF 20 DEG.) AND SLOPE COHERENCE

FIGURE 2

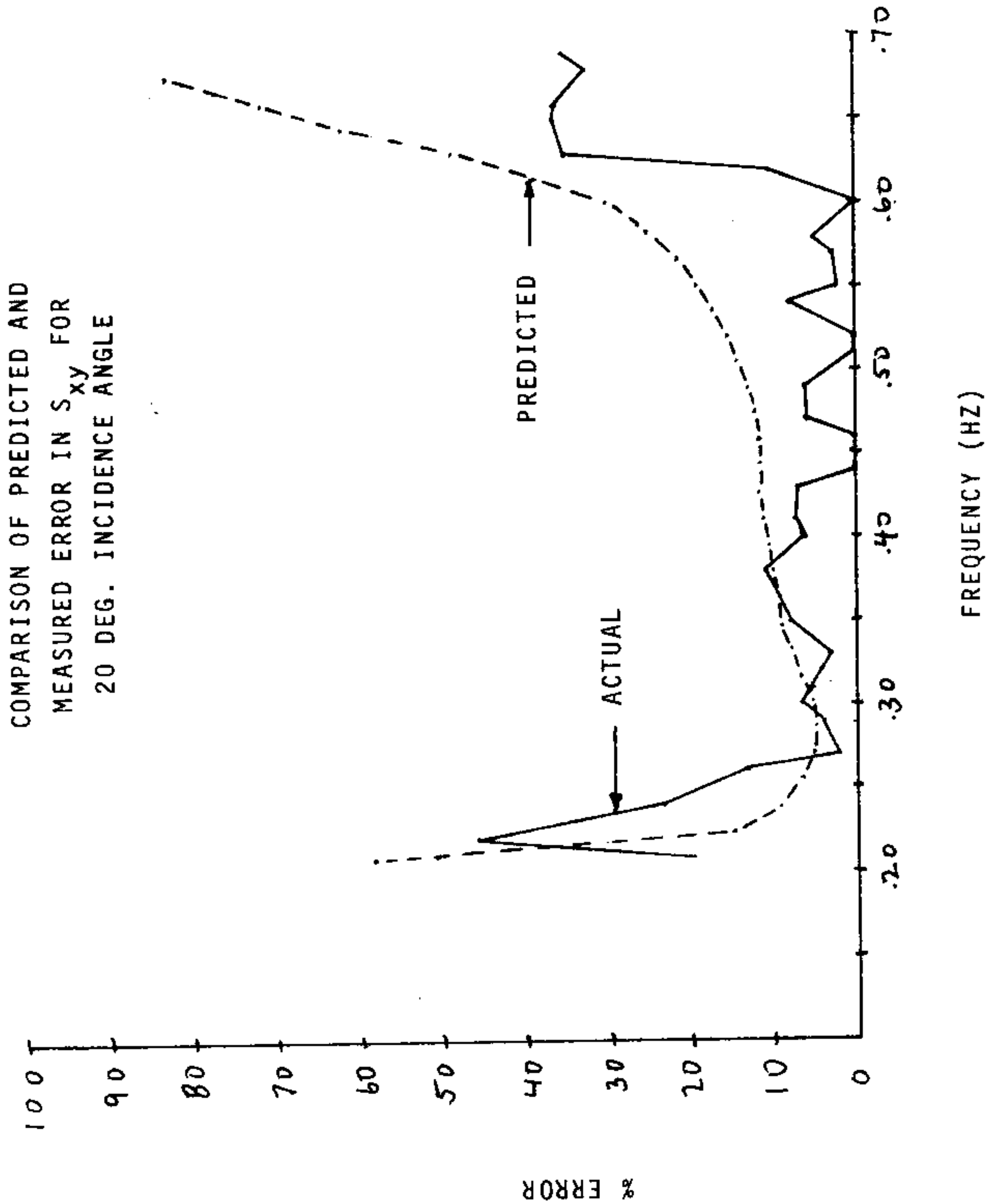

COMPARISON OF PREDICTED AND
MEASURED ERROR IN S_{xy} FOR
20 DEG. INCIDENCE ANGLE
PREDICTED
ACTUAL
FREQUENCY (HZ)
.20
.30
.40
.50
.60
.70
% ERROR
0
10
20
30
40
50
60
70
80
90
100

FIGURE 3

16-17 June 1977
Jenkins, S. and D. Inman

NATIONAL SEDIMENT TRANSPORT STUDY MEETING

TILTING SPAR DIRECTIONAL WAVE SENSOR

Introduction

The objective of this research has been to perfect a compact, low cost, easily installed and maintained directional wave sensor suitable for deployment along the nation's coast lines for monitoring wave climate. The tilting spar wave energy-directional sensor consists of a surface piercing buoyant spar attached to bottom weights by a univeral joint that permits response to wave motion. The motion of the spar, sensed by two accelerometers, gives wave direction, while a pressure sensor provides wave energy. The data may be transmitted to shore by telemetering or by bottom laid cable.

There has been an ever increasing need for such coastal wave climate in all aspects of coastal planning, ranging from the assessment of environmental impact statements pertaining to beach erosion and harbor siltation to the siting of new LNG terminals, coastal refineries and power plants. The numerous marinas and harbors which line the California coast, requiring millions of dollars each year in dredging maintenance, attest to the fact that these decisions have not in the past been based on adequate wave statistics. Unfortunately, most previous technology for gathering these wave statistics is restricted from such broad range application. For example, line arrays of bottom mounted pressure sensors can gather extremely accurate statistics on wave height and direction but are difficult to install and are prone to frequent breakdown because of excessive complexity. Remote sensing of the sea surface by airborne radar is prohibitive in cost with data acquisition limited by aircraft availability and endurance. Finally, the numerous deep water wave observations from ships and wave rider buoys, as well as those from shore observers, are inaccurate in directional and/or frequency resolution.

The tilting spar employed in the Shelf and Shore (SAS) System, (Lowe, Inman and Brush, 1972), developed under previous Sea Grant support, offers a viable alternative to these technologies. The SAS spar is a buoyant, air filled filament glass pipe which houses a telemetery package and antenna in the portion of the spar extending above the free surface. Throughout five years of field testing the spar has proven itself to be a secure structure for instrumentation in near shore waters, repeatedly operating through storm conditions with waves as high as 3 meters.

The tilting spar directional wave system can be used in either of two modes for data link to shore: by cable, or by radio telemetry. The system could be manufactured in quantity in the cable mode of data link at an estimated unit price of $5,500.00 with a 350 meter length cable. In the telemetry data link mode the estimated unit cost is $6,000.00, including the shore receiver.

The pair of orthogonal accelerometers in the directional package permits alignment, maintenance and trouble shooting of all instrumentation to be accomplished quickly and with a high degree of accuracy from a small boat. With the accelerometers both the history and the spectrum of the motion induced in the spar by the waves can be determined. The fundamental task of this research was to learn how the physical parameters of the spar (size, shape, weight, and mooring depth) should be selected so that the motions excited in the spar are representative of the wave motion at a given depth of water. When this is accomplished, the spar motion can be used directly to infer the desired wave statistics.

Design Criteria

A theory was developed for an optimum response of the spar (Jenkins and Inman, in preparation). The optimization was based on obtaining a response which resulted in zero net drag forces acting over the length of the spar. These drag forces result from relative motion between the spar and the water and are particularly undesirable because they are non-linear, causing the spar to move out of phase with the water motion, and inducing secondary higher frequency oscillations. To eliminate net drag forces, it was shown that the spar should be made to follow the horizontal wave motion at a particular depth, which is here referred to as the null point of the drag moment (Figure 1). The moment about the bottom due to drag resulting from the relative motion above the null point exactly cancells the drag moment from opposing relative motion below the null point. The depth of the null point varies with the vertical rate of decay of the wave motion. Accordingly, the null point of the drag moment was found to depend upon the wave length (or frequency) encountered at a given mooring depth, h, as in Figure 2.

It can be shown that the spar must have no net buoyancy if it is to follow the wave motion at the drag moment null point over all possible incident wave frequencies. However, given that a certain amount of buoyancy must be retained to keep the spar upright, in theory the most practical alternative is to keep the center of buoyancy as close to the bottom as possible, and operate at a mooring depth comparable to the incident wave length. The minimal buoyancy which must be retained, together with the maximum mooring depth acceptable for a given location, essentially define the low frequency cut off which is found to be $\sigma = \sqrt{\varepsilon g/h}$, where σ is the radian frequency for the incident wave, g is the acceleration of gravity, h is the water depth, and $\varepsilon = (\rho - \rho_s)/\rho$ is the ratio of the density difference between the water, ρ and the spar, ρ_s, to the density of the water. A further consequence of buoyancy is the phenomena of a natural frequency at which the spar can be excited to excursions which greatly exceed those of the water motion at the null point. Fortunately, the design criteria which lead to a low cutoff frequency, namely relatively small ε and large h, were also found to enhance a condition of over damping, which suppresses resonance near the natural frequency.

Finally, the high frequency response cutoff for the spar was found to be limited by the vortex shedding frequency resulting from wake formation at depths where significant relative motion exists between the spar and the water. Vortex shedding introduces spurious longshore energy into the accelerometer records at the shedding frequency and can be displaced to frequencies beyond the regime of wind waves by using relatively small spar diameters. The radian shedding frequency, σ_s, is found to be given by the Strouhal relation $\sigma_s = 0.1\ \sigma d_0/D$ where $\sigma = 2\pi/T$ is the radian frequency of the waves, d_0 is the orbital diameter at the null point, and D is the spar diameter. However, the optimum response theory places a limit on the smallest permissible spar diameter as $D = -d_0/\log \varepsilon$, before drag effects contaminate the response.

Field Test and Results

With the above expectations from theory, a weakly buoyant ($\varepsilon = 0.4$) "design" spar at a depth of 15 meters was field tested in March and April, 1977, off Torrey Pines State Beach, California, and compared with an off-design ($\epsilon = 0.6$) spar in 10 meters. Both spars were referenced to a five element line array of bottom mounted pressure sensors located at the 10 meter depth. The line array gave estimates of wave direction spectra which served as a ground truth against which the performance of the two spars could be evaluated. Mean wave directions were calculated from the line array by averaging over the direction spectra representative of 34 minute length records with 32 degrees of freedom. Ground truth mean wave directions appropriate for evaluating results from the design spar were obtained after shoaling the wave direction spectra out to 15 meters depth before averaging over direction for a mean value. Mean wave direction estimates were calculated from the motion of the two spars by taking the vector sum at each frequency of the rms amplitudes from the orthogonal pair of accelerometers contained in the telemetry package. It was necessary to correct these rms amplitudes for the component of gravity superimposed when steady currents give the spars a non zero mean tilt angle, thereby tilting the axes about which the accelerometers sense the resulting motion.

A band by band comparison of the mean directions obtained in the above manner from the 15 meter "design" spar and the array appear in Figure 3 for a 34 minute run during a local storm on 25 March 1977. Agreement in mean direction between the design spar and the array appears quite good over the range of periods which the linear ground truth array can resolve, 6 to 18 seconds, especially under the principle spectral peaks. Furthermore, the accelerometer spectra is found to reproduce the major features of the pressure spectra with the appropriate relative energy.

Mean wave directions from the design spar and the array for principle spectral peaks from a number of varied runs are compared in Table 1. These results show close agreement in mean direction even for highly spread, multi modal direction spectra.

The range of frequencies over which the design spar can gather wave direction information is limited by the range over which it will respond in phase with the horizontal wave particle motions. The study showed that a tilting spar directional wave sensor could be designed for a variety of frequency ranges by adjusting the buoyancy, mooring depth, and diameter of the spar. The experiments established the useful range for this particular spar to be from 5.0 to 20.0 seconds. Undoubtedly, the design spar gave reliable directional data to lower periods, but there was no ground truth for evaluating direction for periods below 5 seconds. A pressure sensor mounted near the null point of the spar could extend the utility of directional data into the extreme high frequency portion of the spectrum.

60% of the mean wave direction estimates derived from the off-design, highly buoyant spar in 10 meters of water also compared favorably with those measured by the line array. When estimates from the 10 meter spar did not compare well, the frequency band for the direction in question appeared at a small integer multiple of significant low frequency energy.

Although the weakly buoyant deep water spars appear less sensitive to resonance and frequency contamination, a possible limitation to their application would be in locations where strong steady currents (>50 cm/sec) would lean them over at large constant tilt angles. However, in moderate steady currents (<20 cm/sec), the zero frequency response or mean tilt of the spar may serve as a useful measure of the vertical average of these currents. Figure 4 shows a systematic variation of the mean tilt angle in the onshore and longshore directions with the mean onshore and longshore currents measured 4 meters below mean sea level during the 16-31 March 1977 runs. These currents were of tidal periodicity, lacking significant vertical structure other than a bottom boundary layer. The effect of baroclinic motions during warm summer months on variations in mean tilt angle with mean current, however, requires further study.

References

Lowe, R. L., D. L. Inman and B. M. Brush, 1972, "Simultaneous data system for instrumenting the shelf", Proc. 13th Int. Conf. on Coastal Eng., Amer. Soc. Civil Eng., Vol I, p 95-112.

Table 1: Mean Direction Comparison for Principle Spectral Peaks

Run	Peak	Period (sec)	Mode	5 Element Array Mode Direction	5 Element Array Mean Direction	Design Spar Mean Direction
16 Mar 77 17:32 *Mean Currents: 1.5 cm/sec On 2 cm/sec S.	1	14.8	1	18.5°S	21.6°S	20.9°S
	3	11.0	1	37.5°N	2.9°N	3.1°N
			2	6.5°N		
			3	40.5°S		
	2	7.7	1	12.5°N	7.2°N	7.1°N
			2	7.5°S		
			3	43.5°S		
25 Mar 77 9:24 Mean Currents: 1 cm/sec On 6.2 cm/sec S.	3	12.0	1	7.4°N	2.7°N	1.6°N
	4	8.8	1	10.8°N	2.1°N	2.2°N
			2	9.9°S		
			3	22.2°S		
	2	7.7	1	8.6°S	2.3°N	2.1°N
			2	14.1°N		
	1	6.5	1	17.1°N	3.9°N	2.9°N
			2	6.7°N		
			3	6.0°S		
			4	15.3°S		
25 Mar 77 9:58 Mean Currents: 1 cm/sec On 6.2 cm/sec S.	2	12.0	1	7.4°N	2.6°N	2.7°N
	3	10.1	1	9.7°N	1.5°N	3.7°N
			2	11.2°S		
	1	6.5	1	14.7°N	2.2°N	5.2°N
			2	10.6°S		
			3	24.6°S		
25 Mar 77 10:32 Mean Currents: 0.5 cm/sec Off 8.5 cm/sec S.	3	12.0	1	7.3°N	2.6°N	1.4°N
	4	10.1	1	8.5°N	1.5°N	1.8°N
			2	11.2°S		
	2	7.3	1	16.3°N	2.4°N	2.0°N
			2	5.6°N		
			3	23.9°S		
			4	13.2°S		
	1	6.5	1	14.7°N	2.1°N	2.0°N
			2	10.6°S		
			3	24.5°S		
29 Mar 77 11:21 Mean Currents: 3 cm/sec On 3 cm/sec N.	3	14.8	1	6.3°N	4.3°S	2.2°S
	1	10.1	1	9.8°N	4.7°S	1.7°S
	2	8.2	1	5.0°N	5.9°S	2.6°N
			2	13.2°S		

* "N","S", "On", "Off" signify longshore to the north or south and on or offshore currents.

Table 1: Mean Direction Comparison for Principle Spectral Peaks (Continued)

Run	Peak	Period	Mode	5 Element Array Mode Direction	5 Element Array Mean Direction	Design Spar Mean Direction
29 Mar 77 11:55 Mean Currents: 3.3 cm/sec On 2.9 cm/sec N.	2	14.8	1	3.7°N	1.1°S	5.4°S
	1	11.0	1	9.9°N	3.4°N	2.4°S
			2	5.1°S		
	3	7.3	1	16.5°N	5.1°N	2.1°S
			2	12.1°S		
29 Mar 77 12:29 Mean Currents: 3.3 cm/sec On 2.2 cm/sec N.	2	14.8	1	7.7°S	5.2°S	3.4°S
	1	11.0	1	6.1°N	0.3°N	0.4°N
	3	8.2	1	10.8°N	5.2°N	0.5°N
			2	7.5°S		
	4	6.5	1	17.5°N	3.1°N	5.6°N
			2	12.0°S		
			3	9.2°N		
31 Mar 77 12:26 Mean Currents: 2.6 cm/sec On 2.5 cm/sec S.	2	14.8	1	14.1°S	13.0°S	10.9°S
	1	11.0	1	9.9°N	4.4°N	3.5°N
			2	7.6°S		
	3	8.8	1	10.9°N	6.3°N	2.8°N
31 Mar 77 13:01 Mean Currents: 3.3 cm/sec On 3.0 cm/sec S.	2	13.3	1	16.7°S	11.0°S	12.4°S
	1	11.0	1	10.0°N	2.9°N	2.2°N
			2	6.4°S		
	3	7.7	1	14.4°N	7.2°N	0.7°N
			2	8.6°S		

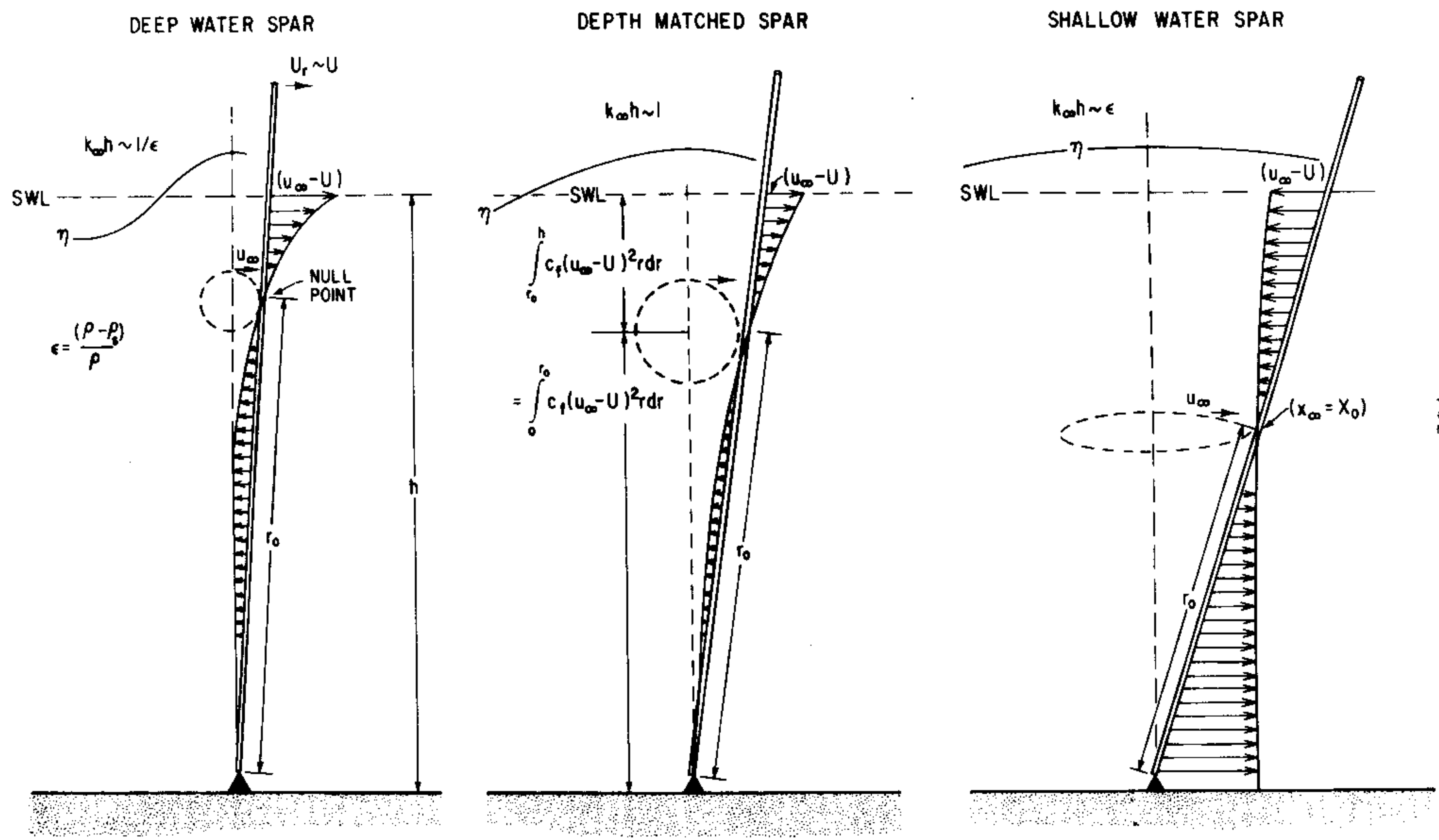


Figure 1. Vertical distribution of the relative velocity, $(u_\infty - U)$, gives rise to a zero net drag moment when the spar follows the horizontal wave particle excursions, x_∞ at r_o, the drag moment null point. Variation of the relative velocity distribution with wave frequency gives rise to three distinct scale regimes having different null points.

MM.94-9a

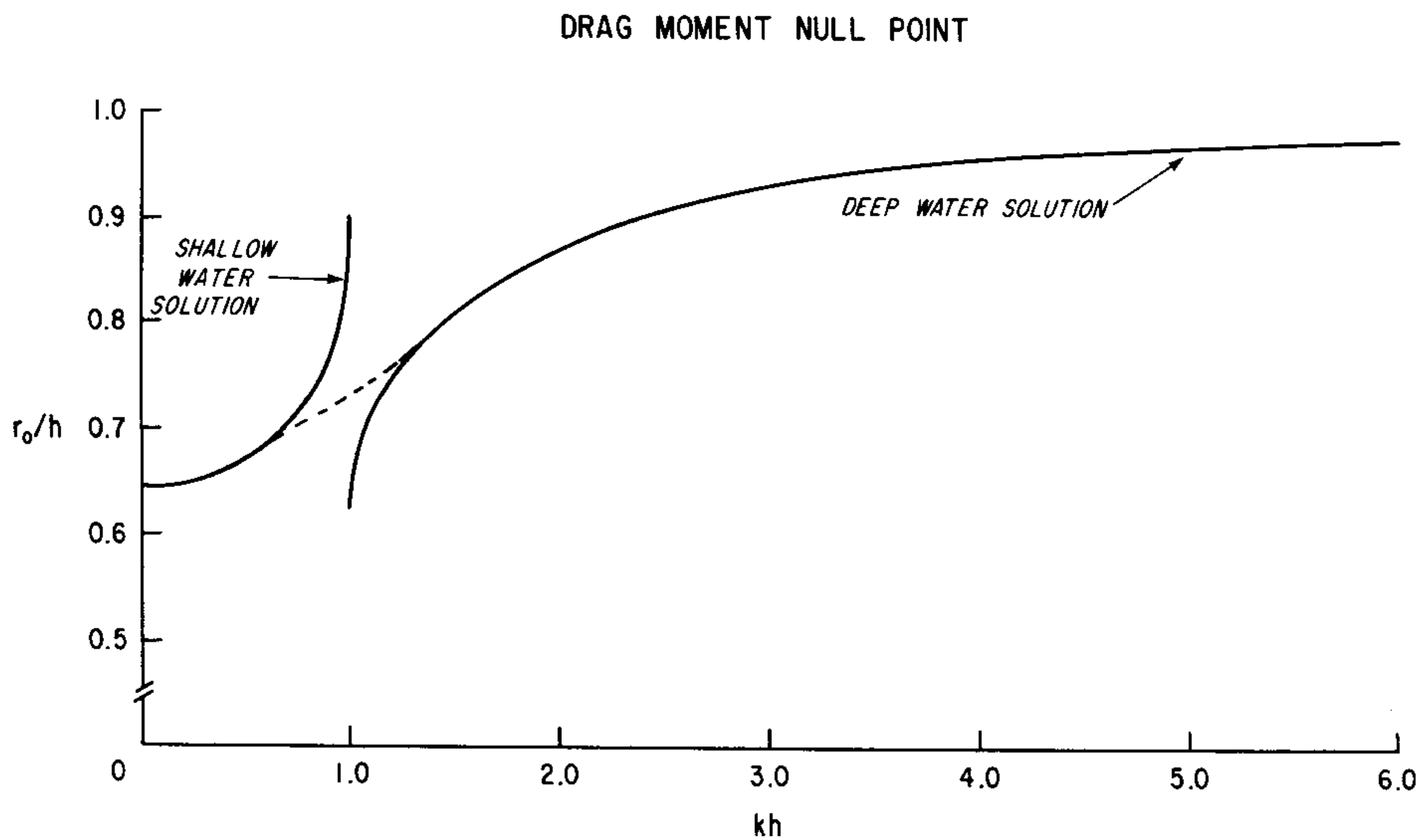


Figure 2. Asymptotic solution for the drag moment null point, r_o, as a function of the incident wave number, $k = 2\pi/\text{wavelength}$, encountered at a mooring depth, h.

77.97-8

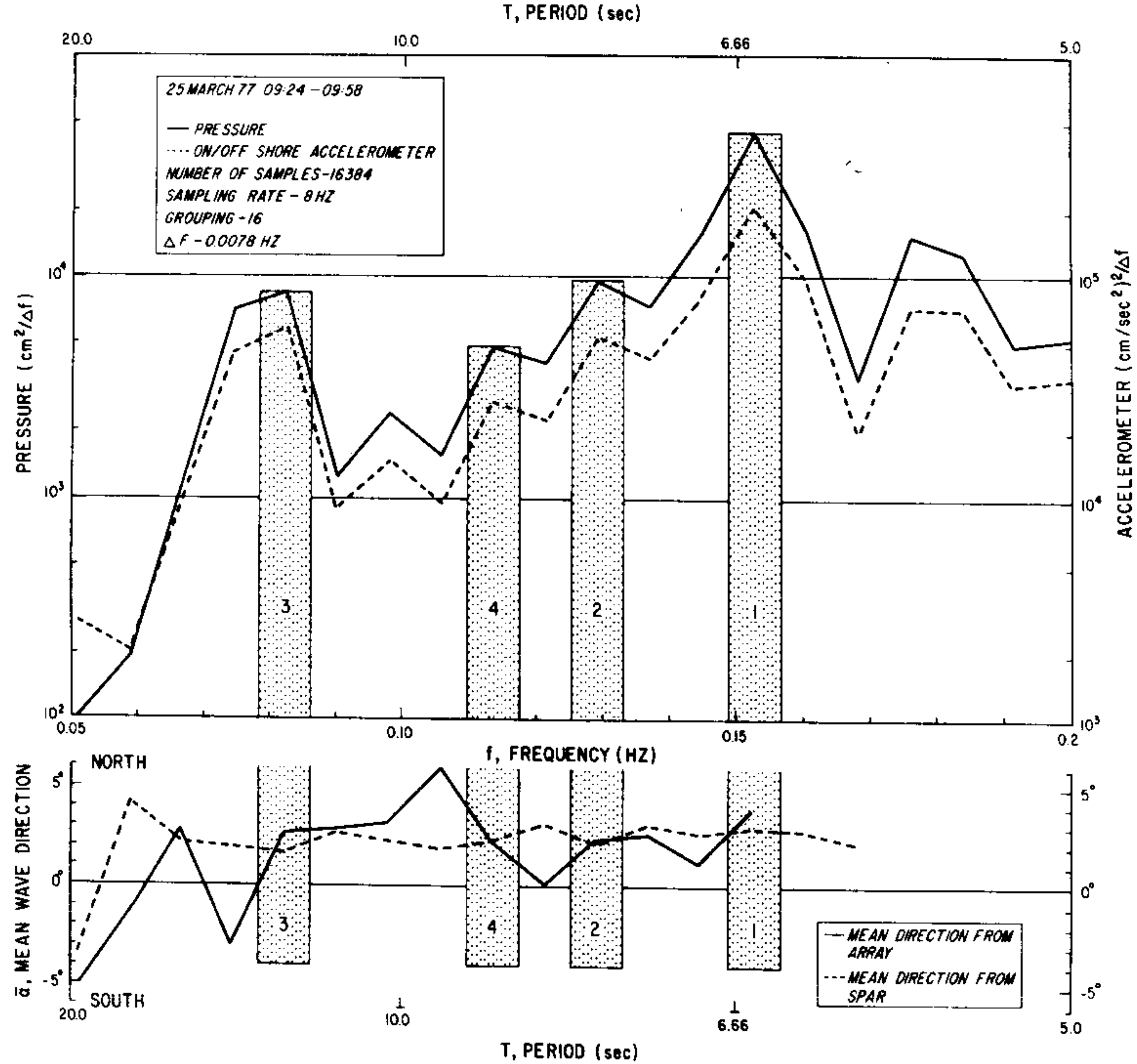


Figure 3. ABOVE. Band by band comparison between the autospectra of the pressure with that of the on off shore accelerometer in the design spar moored in 15 meters of water. BELOW: Mean wave direction obtained by averaging the direction spectra from a 5 element line array compared with mean wave direction from the vector sum of the rms amplitudes from an orthogonal pair of accelerometers in the design spar. Direction spectra from array were measured in 10 meters and shoaled out to 15 meters for comparison with the design spar.

17.94-18

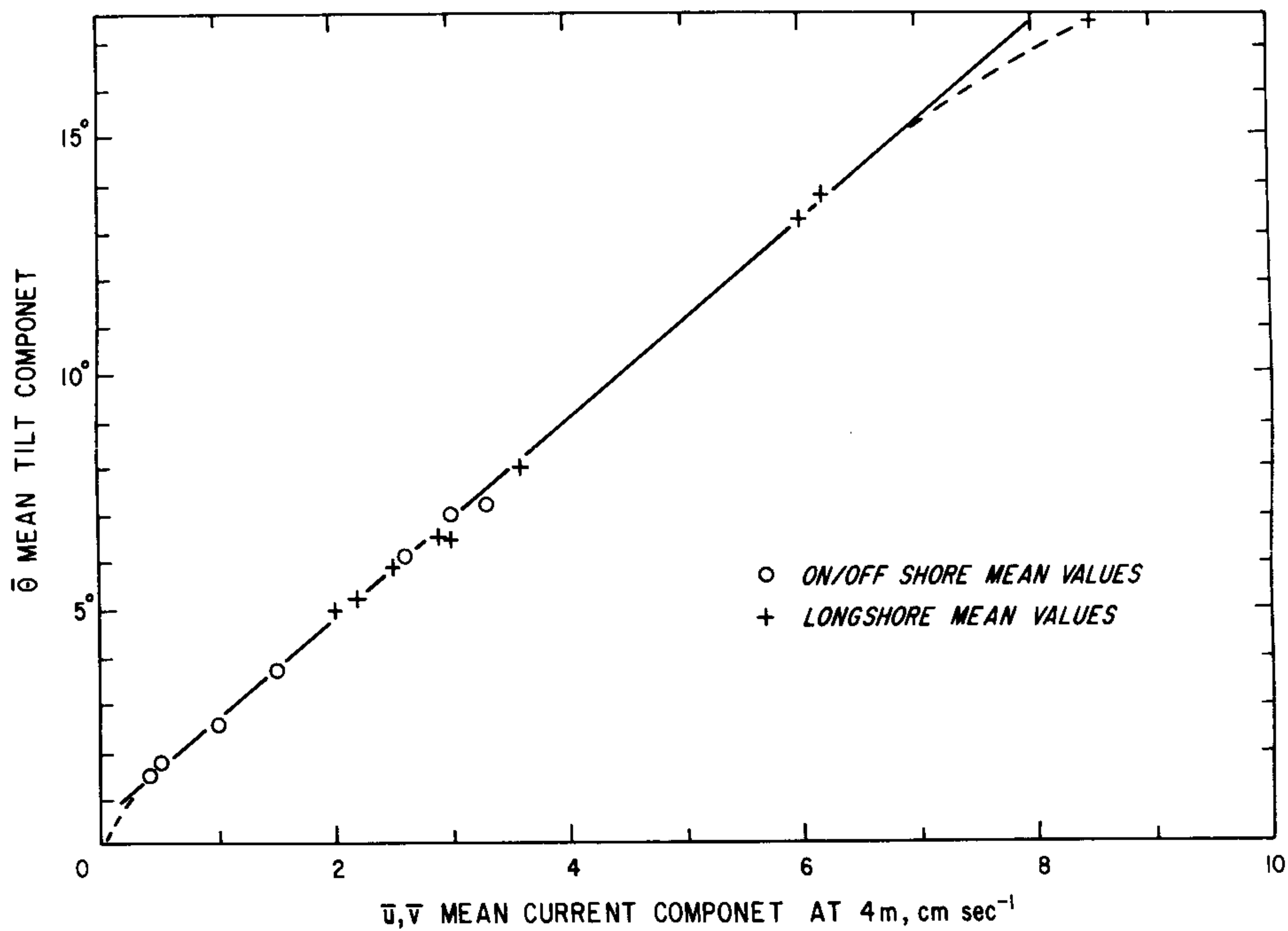


Figure 4. Onshore and longshore zero frequency response of the 15 meter design spar to onshore and longshore steady currents measured at 4 meters depth. Mean tilt and currents taken over 34 1/2 minute records between 16 and 31 march 1977.

77-94-17

MEASUREMENT OF IMPOUNDED SEDIMENT

R. O. BRUNO
COASTAL ENGINEERING
RESEARCH CENTER

Introduction: Impounded sediment implies the presence of a man-made structure or geomorphic feature in the nearshore zone which impedes the longshore movement of sediment. This structure and resulting impoundment occurs in an environment of shoaling or breaking waves. Instrumentation and methodology for high density measuring of bathymetry and topography in this deposition zone is needed to determine impoundment geometry.

This paper is intended to discuss state-of-the-art of nearshore surveying ; I will not present a historical development. Suffice it to say non-electronic techniques of positioning and sounding cannot normally provide data densities and accuracies of modern electronic equipment.

Further, I would like to highlight in this presentation problems unique to surf zone surveying.

Survey Vehicle: The factor that makes this work unique is obtaining measurements near and through the surf zone. Using a boat as the survey vehicle will only permit data collection ourside of the surf zone. However, to get a complete picture of impoundment geometry necessitates continuous data collection from shore through the surf to deep water. This means it is necessary to use an amphibious vehicle which is capable of traversing this zone. Without resorting to newly developed military vehicles, I believe the only amphibious vehicle for ocean shore work is the LARC V (Lighter Amphibious, Resupply Cargo). This extremely versatile vehicle is an excellent working platform for nearshore work.

Instrumentation: For a complete modern and/or automated hydrographic survey system, three basic components are required: horizontal position and vertical depth measuring devices, a data acquisition device, and a data logging device. It is also highly desirable to have vehicle steering feedback and data monitoring equipment. If the survey area includes the beach and foreshore, land survey instruments are required. In many automated systems several components are combined in one instrument. Recently several authors have discussed modern instrumentation for hydrographic surveys (Hart and Downing, 1976; Gilmore, 1977; Heinz, 1977). Table 1 is taken from Heinz (1977) which gives a summary of equipment manufacturers. An example of hydrographic survey system hardware is presented in the Appendix.

Expenses of fielding a hydrographic survey crew in salaries, mobilization and vehicle cost are the most significant part of a long term impoundment monitoring budget. Therefore, extra costs of purchasing reliable instruments, spare parts and redundant systems are a wise investment. Instruments which do not need specially trained personnel to operate them will also prove cost effective. Examples of these are data acquisition computers, which are programmed with a high level language instead of assembly language, or instruments with circuit card replacement spares that do not require an electronics technician to maintain.

TABLE 1

Manufacturers of electronic hydrography equipment

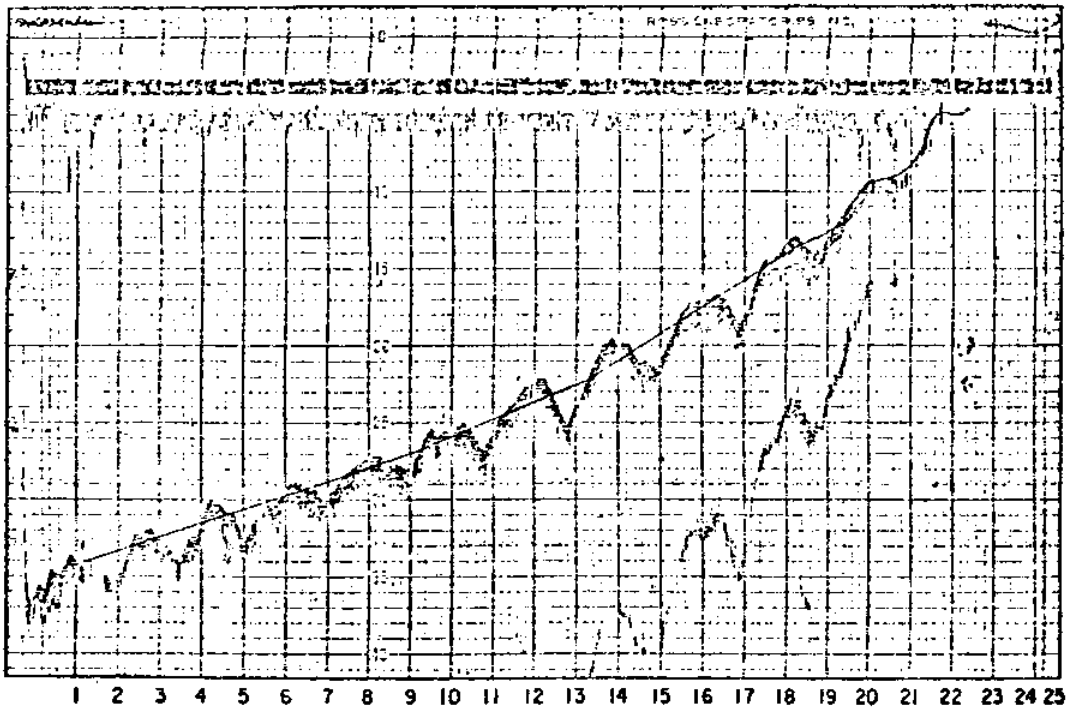
Line-of-Sight Positioning Systems		
ACCI		
CRENCO, Inc.	Alexandria, VA	703/548-2544
Cubic Industrial Corp.	San Diego, CA	714/279-7400
Del Norte Technology, Inc.	Euless, TX	817/267-3541
Motorola, Inc.	Scottsdale, AZ	602/949-3181
Navigation Management, Inc.	Anthony, FL	904/732-0904
Tellurometer Division	Happauge, NY	516/231-7710
Associated Controls & Communications	Lynn, MA	617/636-3111
Nonline-of-Sight Positioning Systems		
Cubic Industrial Corp	San Diego, CA	714/279-7400
Decca Survey Systems	Houston, TX	713/783-8220
HydroCarta Corp	Houston, TX	713/771-1263
Odom Offshore Surveys, Inc	Baton Rouge, LA	504/766-6330
OMI		
Sercel, Inc.	Houston, TX	713/688-9433
Teledyne/Raydist	Hampton, VA	703/723-6531
Tracor, Inc.	Austin, TX	512/962-2800
Computer Controlled Hydrographic Survey Systems		
Cubic Industrial Corp	San Diego, CA	714/279-7400
Decca Survey Systems	Houston, TX	713/783-8220
Digital Equipment Corp.	Maynard, MA	617/897-5111
HydroCarta Corp.	Houston, TX	713/771-1263
Motorola Inc	Scottsdale, AZ	602/949-3181
Teledyne/Geotech	Alexandria, VA	703/836-3882
Microprocessor Controller Survey Systems		
Decca Survey Systems	Houston, TX	713/783-8220
Morgan Consulting, Inc	Fort Walton Beach, FL	904/242-1413
Motorola, Inc	Scottsdale, AZ	602/949-3181
Data Logging Systems		
Cubic Industrial Corp	San Diego, CA	714/279-7400
Morgan Consulting, Inc	Fort Walton Beach, FL	904/242-1413
Motorola Inc	Scottsdale, AZ	602/949-3181
Ross Laboratories, Inc.	Seattle, WA	206/324-3950
Teledyne/Geotech	Alexandria, VA	703/836-3882
Satellite Positioning System		
Magnavox	Torrance, CA	213/328-0770
Depth Measurement		
Bludworth Marine Division	Linden, NJ	201/925-8650
Edo Western Corp.	Salt Lake City, UT	801/486-7481
Geophysical Survey Systems, Inc.	N. Billerica, MA	617/667-4341
Innerspace Technology, Inc.	Waldwick, NJ	201/447-0398
InterOcean Systems, Inc.	San Diego, CA	714/299-4500
Raytheon Corp	Portsmouth, RI	401/874-8000
Ross Laboratories, Inc	Seattle, WA	206/324-3950
Subbottom Profilers		
Del Norte Technology, Inc.	Euless, TX	817/267-3541
Edo Western Corp.	Salt Lake City, UT	801/486-7481
EG&G International	Waltham, MA	617/271-5000
Klein	Salem, NH	603/893-6131
ORE	Falmouth, MA	617/548-5800
Side Scan Sonar		
Edo Western Corp.	Salt Lake City, UT	801/486-7481
EG&G International	Waltham, MA	617/271-5000
Gould	Shadyside, MD	301/269-0570
Klein	Salem, NH	603/893-6131
ORE	Falmouth, MA	617/548-5800
Westinghouse (Oceanic Division)	Annapolis, MD	301/765-1000
Multibeam Depth Measurement		
Chesapeake Instrument Corp.		
C-Tech Limited	Cornwall, Ontario	613/933-7970
General Instrument Corp.	Westwood, MA	617/326-7815
Raytheon Corp.	Portsmouth, RI	401/874-8000
Ross Laboratories, Inc.	Seattle, WA	206/324-3950
Land Survey Supplies		
Bernsten Cast Products	Madison, WI	608/249-9233
Hewlett Packard	Kenner, LA	504/443-6201
Tellurometer Division	Happauge, NY	516/231-7710
Cubic Industrial Corp.	San Diego, CA	714/279-7400

(after Heinz, 1977)

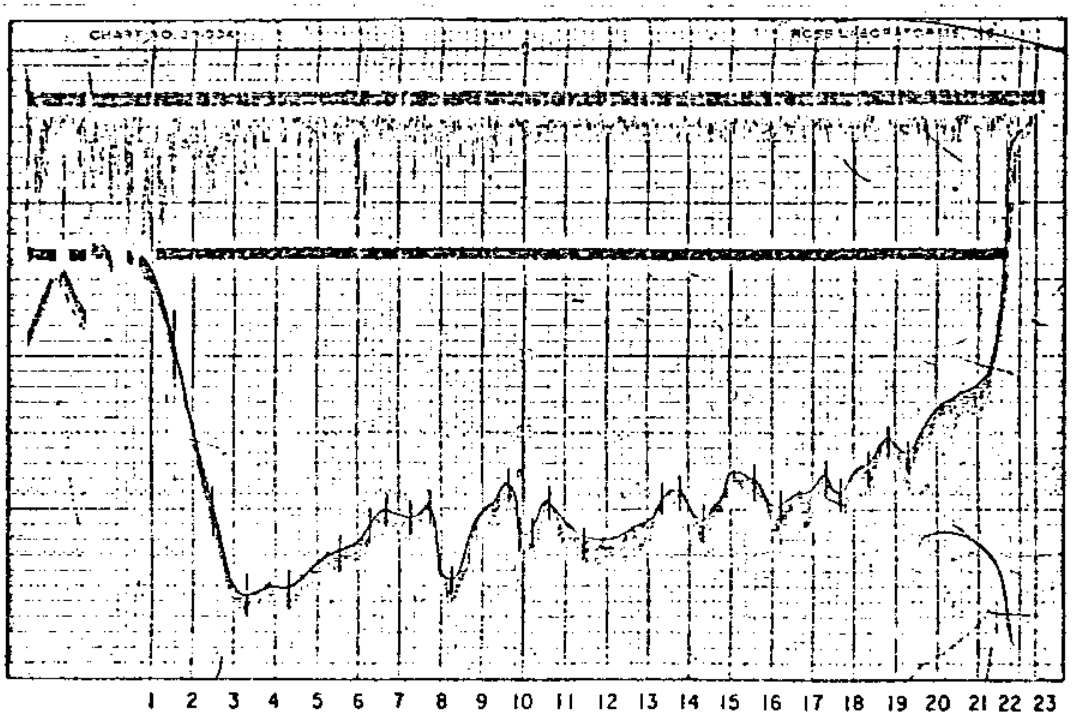
Survey Procedure: Prior to conducting the survey, tide gage, position instrumentation, and fathometer should be calibrated. In areas where water density (i.e. salinity and temperature) are expected to vary, the fathometer must be calibrated daily or perhaps more frequently. One of the largest systematic errors found in nearshore surveying lies in poor fathometer calibration. Fathometers should be calibrated onboard the survey vessel, at the survey site, and using a target lowered under it at depth increments (referred to as a bar check). This calibration should span the complete range of water depths expected. The importance of calibration by bar check at the survey site is often overlooked.

Vehicle track lines and total area of survey coverage should be planned prior to the survey. This plan must include coverage of the entire area of impoundment; in most cases this means the survey will include an area of depths greater than 10 meters to the backbeach. In most locations depth contours are "regular" in the alongshore direction. If this is true, maximum information can be obtained by following closely spaced shore-normal track lines. Also data analysis costs can be minimized if data is taken from parallel equally spaced track lines; usually, a spacing of 30 meters is adequate. Saville (1953) discusses errors which can arise from survey line spacing. If bottom contours are not regular, additional tracklines are required in the alongshore direction.

Since the nearshore is a highly dynamic zone, significant changes in bathymetry can occur over a tidal cycle. Ideally all survey data should be collected within a few hours, but of course in most instances this is impossible. If the whole area of impoundment cannot be surveyed



RANGE 124+00 – FATHOMETER RECORD WITH WAVES



RANGE 104+00 - FATHOMETER RECORD WITHOUT WAVES

Figure 1. Fathometer Record of Regular Bottom with Waves and Irregular Bottom without Waves.

in a short time, effort should be made to identify and survey the most dynamic zone over the shortest time possible. For example at a detached breakwater the zone in the region of the upcoast end experiences rapid change. This whole zone should be surveyed on the same day. The area downcoast in the shadow of the breakwater changes less rapidly and can be surveyed over several days without any significant error.

To further eleminate errors due to beach dynamics, each profile line should be surveyed from back beach to offshore contonuously. Using an amphibious vehicle this is accomplished by sounding with the fathometer shoreward until the fathometer record becomes unintelligible. At this point water depths are shallow and a rodman on the deck can hold a survey rod on the bottom to continue the transect shoreward.

An important key to the successful measuring of impoundment is to employ a survey supervisor who is briefed on all aspects of the project. The good judgement and high motivation of this man is the only insurance that accurate data is being collected.

Survey quality can also be improved by only surveying under the most ideal weather conditions. If all equipment can be assembled in a ready state on site and deployed when weather conditions are perfect high quality data will be collected. Of course, it is often too costly to wait for these ideal weather conditions.

Data Analysis: During data analysis, raw data is adjusted according to tide readings and pre-survey instrument calibrations. Then depth record fluctuations due to waves must be corrected. To date the largest single source of errors in state-of-the-art nearshore surveying occurs in resolving wave influence. Figure 1 illustrates that in some instances it is virtually impossible to resolve bottom features.

Effort has been made to investigate the possibility of establishing a reference datum above the water surface with a laser. The California Department of Navigation and Ocean Development funded a laser datum feasibility investigation conducted by US Navy, Pacific Missile Test Center, under the direction of CERC (report unpublished). Although the study showed the concept might be feasible, the fabrication of a prototype has not been funded. Presently this fluctuation in the depth record is simply smoothed for data analysis.

A technique which can be used to eliminate random data errors is to plot difference maps of consecutive surveys and scan them for spurious deviations. Figure 2 illustrates how a three dimensional difference plot can be used to identify erroneous data.

Summary: There is a wealth of modern electronic survey equipment available on the market today, but a system used to monitor impoundment must be selected to perform in the extremely harsh nearshore zone. Total coverage of the nearshore requires the use of an amphibious vehicle, and quality of data collected can only be insured by a highly motivated survey supervisor and field crew.

Some ambiquity of bottom elevation is unavoidable as long as the water surface is used as a muesurement datum.

Acknowledgements: This paper resulted from research conducted at the Coastal Engineering Research Center of the U.S. Army Corps of Engineers. Opinions expressed are those of the author and are not to be construed as an official Department of the Army position. Mention of brand names and products does not constitute endorsement by the Department of the Army.

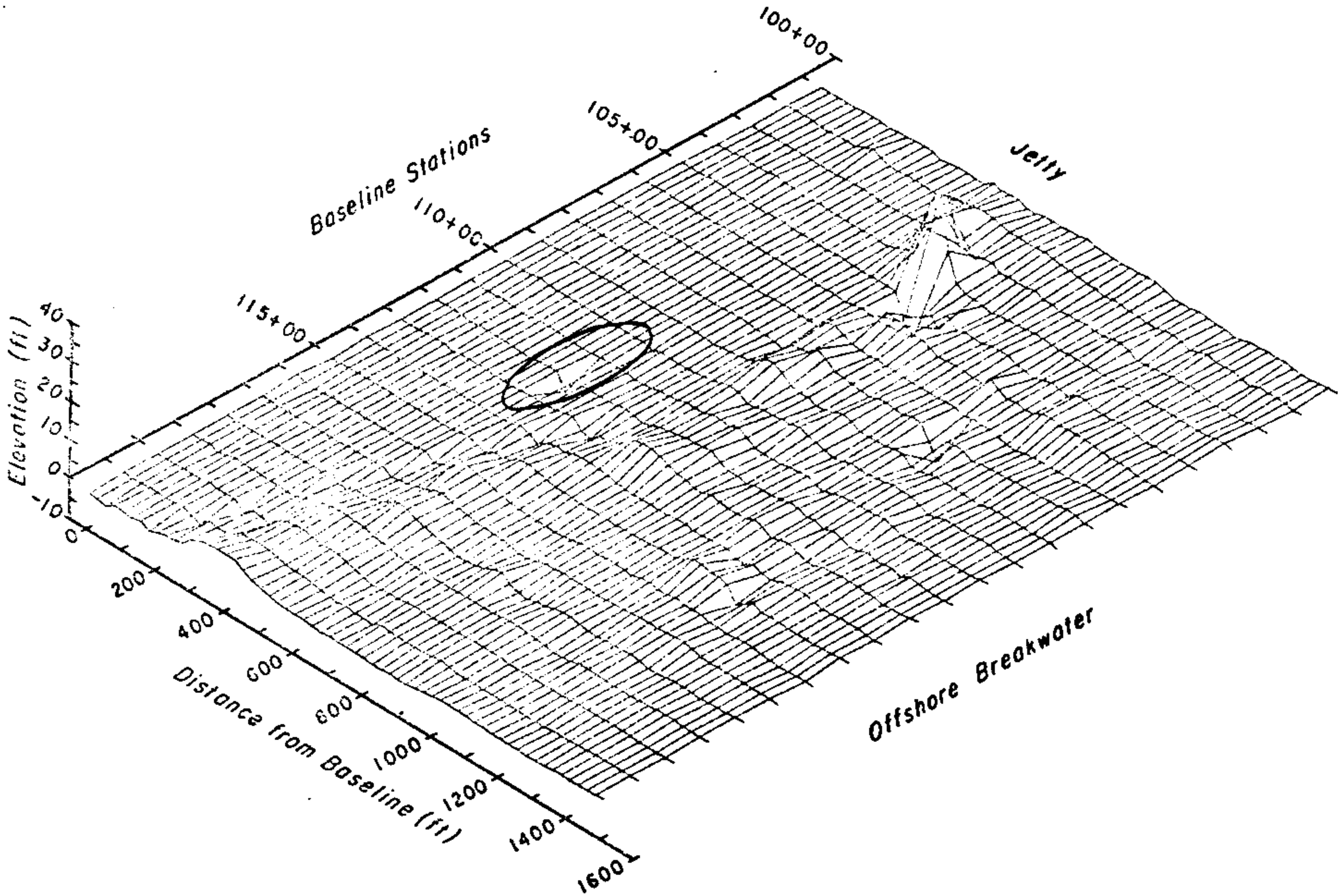


FIGURE 1 - Difference Map of Consecutive Nearshore Surveys

Appendix

COASTAL ENGINEERING RESEARCH CENTER (CERC) SYSTEM

The CERC surveying equipment was originally assembled for Radioisotopic Sand Tracer (RIST) work (Judge, 1975) and later was employed to study longshore sand transport (Bruno and Gable, 1976) at Oxnard, California. Some modifications to system hardware were made during the latter study to improve system reliability. The equipment is deployed on a LARC-V amphibious vehicle to traverse the surf zone. Data is telemetered to a shore based van where it is monitored and recorded.

Position of the LARC is determined using a Motorola Miniranger III which is a line-of-sight microwave ranging device. Miniranger III outputs distances from two portable shore reference stations and has an accuracy of one meter at distances of less than two kilometers.

Water depths are determined by a Ross fathometer which produces both analog and digital output. Nominal accuracy of the fathometer is 0.5% of water depth.

These data are selected at two second intervals by a custom built data acquisition device which was constructed by Oak Ridge National Laboratory. The data acquisition unit also sends a pulse to mark the analog depth recorder with two second readings. As a switch selectable option the data may be recorded on an internal cassette recorder of the data acquisition unit or may be transmitted to shore based receiver.

In the event data acquisition unit fails to function a backup system composed of a digital printer and timer is available. Here the timer sends a synchronous signal to mark the analog depth record and print the range-range data from the Miniranger.

Also available onboard the LARC is a custom built X-Y calculator which automatically displays the vehicle X-Y position coordinates for the driver. The device, built by U.S. Navy, Pacific Missile Testing Center, uses a programmable calculator as its "brains" to convert range-range data of the Miniranger to X-Y coordinates. Unfortunately the slow speed of this device makes it of limited use for navigation. However, with modern microprocessor technology an X-Y calculator could be constructed to give instantaneous position information to the driver.

The most common mode of operation for this system is to transmit the data to the shore station. The heart of the shore receiving station is a PDP-8 Digital Equipment Corporation Minicomputer. Peripheral devices on the PDP-8 include the data telemetry receiver, teletypewriter, cathode ray tube (CRT) scope with memory, cassette tape reader and 7-track magnetic tape drive. During the survey data are received at two-second intervals, and the X-Y position of the vehicle is calculated by the PDP-8. The raw data and calculate position are then stored on magnetic tape for further analysis. The CRT is used to allow the survey supervisor to monitor all data as it is received. The position of the vehicle is plotted on a map view and the digital depth is displayed in one corner of the CRT. It is important to note that through this use of the CRT the data quality of each data point can be assessed in real time. To provide a hard copy of the survey in real time the teletype is used to print the data at ten-second intervals. Data printed include: time in seconds, X-Y coordinates, and depth sounding. An example of this output is shown in Figure A-1.

As survey of profile lines continues shoreward the survey supervisor interrupts the recording of data onto magnetic tape when the fathometer

FIGURE A-1: Example of Real Time Teletype Printout

DATE 9/ 17/ 75 TIME 1211

FIX NO	TSU TIME	RANGE	DIST	DIG DEPTH	ANL DEPTH
1	14470	13072	3846	43.6	
2	14480	13135	3708	43.2	
3	14490	13165	3731	43.7	
4	14500	13167	3828	44.0	
5	14510	13113	3838	43.1	
6	14520	13035	3820	43.6	
7	14530	12963	3736	43.5	
8	14540	12964	3736	43.1	
9	14550	12976	3638	42.5	
10	14560	13021	3560	42.1	
11	14570	13017	3489	41.9	
12	14580	13013	3411	41.4	
13	14590	13024	3340	41.1	
14	14600	13029	3254	40.5	
15	14610	13043	3177	40.2	
16	14620	13029	3103	40.2	
17	14630	13021	3031	39.4	
18	14640	13023	2937	39.1	
19	14650	13003	2873	38.5	
20	14660	13010	2789	38.2	
21	14670	13023	2714	37.5	
22	14680	13023	2630	37.2	
23	14690	13021	2551	35.9	
24	14700	13004	2472	35.7	
25	14710	13008	2395	35.0	
26	14720	13012	2314	34.4	
27	14730	13014	2243	33.4	
28	14740	13212	2157	32.9	
29	14750	13009	2084	31.9	
30	14760	13009	2001	31.1	
31	14770	13006	1924	30.3	
32	14780	13002	1839	29.4	
33	14790	13003	1763	28.8	
34	14800	13003	1686	27.8	
35	14810	13001	1605	26.9	
36	14820	12999	1519	25.8	
37	14830	12998	1444	25.5	
38	14840	12995	1361	23.9	
39	14850	12995	1283	23.7	
40	14860	13008	1204	21.7	
41	14870	13003	1123	21.1	
42	14880	12993	1044	19.5	
43	14890	13001	967	17.9	
44	14900	12995	891	16.2	
45	14910	12995	829	14.2	
46	14920	12991	752	12.3	
47	14930	12998	680	8.9	
48	14940	13002	614	9.3	
49	14950	12993	523	8.3	
50	14960	12997	443	7.0	
51	14970	12997	365	6.9	
52	14980	12996	294	5.4	
53	14990	12998	221	4.6	

record is lost in shallow water. At this point land survey techniques are used to read a survey rod and distance offshore is continuously displayed on the teletype. Each time a rod reading is made the LARC is stopped and its position is radioed to the land survey party by the survey supervisor.

REFERENCES

BRUNO, R.O., and GABLE, C.G., "Longshore Transport at a Total Littoral Barrier", Fifteenth Conference on Coastal Engineering, ASCE, July 1976.

GILMORE, M., "Recording River and Reservoir Water Depth", Civil Engineering ASCE, April 1977, pp 65-66.

HART, E.D., and DOWNING, G.C., "Fourth Hydrographic Survey Conference", U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss., March 1976.

HEINZ, R.A., "Hydrographic Surveying Turns to Electronics", Civil Engineering, ASCE, April 1977, pp 62-64.

JUDGE, C.W., "Use of the Radioisotopic Sand Tracer (RIST) System", U.S. Army Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, Virginia, June 1975.

SAVILLE, T., Jr., and CALDWELL, J.M., "Accuracy of Hydrographic Surveying in and Near the Surf Zone", U.S. Army Corps of Engineers, Beach Erosion Board, Washington, D.C., March 1953.

PROPOSED FIELD EXPERIMENT

by

Edward B. Thornton
Naval Postgraduate School
Monterey, CA 93940

Both micro and macroscale field experiments are planned under the Nearshore Sediment Transport Study. Microscale experiments will be performed to obtain a basic understanding of the forcing and response functions of sediment transport in order to properly parameterize the problem. Detailed measurements of the forcing function will include waves, flow velocities, wind and tides; direct measurements of the suspended and bedland transport will simultaneously be made. A second type of experiment will be to make gross sediment transport determination using techniques such as impoundment. The impoundment studies are referred to as macroscale sediment measurements in which net accumulation with time of sediments by an effective trap will be made at the site of each major experiment. Simultaneously the waves and velocity fields will be measured on the microscale during the macroscale experiments. Because of the complexity of the nearshore zone and our general lack of understanding of the the flow mechanisms and sediment response, the field sites will be selected on the basis of straight coast lines having simplified bottom profiles.

Figure 1 shows schematically the envisioned program of measuring the forcing and response functions. An engineering predictive model is to be simultaneously pursued with the field programs. The field measurements will be used to determine empirical transfer functions and also to provide the necessary input to the theoretical model for improving and testing. The end product is to be an engineering formulation of sediment transport which will undoubtedly be a blend of theory and empiricism.

In the design of any measurement program, it is necessary to measure with the proper spatial and temporal resolution. Minimum spatial and temporal resolution must be correctly specified in order to avoid aliasing of time and space information. Areal extent and length of experiments is based on obtaining representative or adequate, statistical samples of the phenomena of interest. Table 1 is a list of the time and space scales to be expected for the various forcing and response functions in

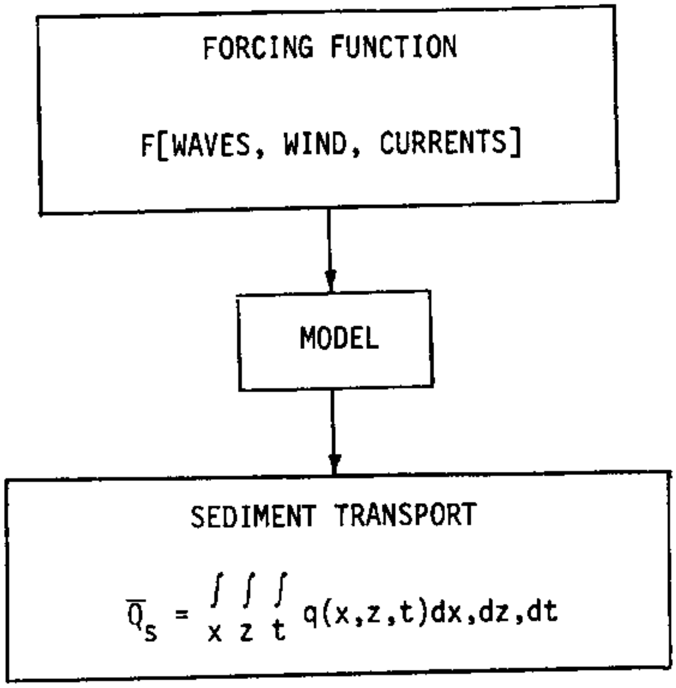


Figure 1. Sediment response to forcing functions

the nearshore regime. It will be noted that the table is not very well filled in as our knowledge of the appropriate space/time scales for many of the various phenomena are not well understood. An objective of the first experiments is to obtain better information on space/time scales so that subsequent experiments can be better designed.

A major task will be instrumentation development. Adequate instrumentation exists to measure waves and flow velocities but the instrumentation to measure suspended and bed load transport is essentially non-existent. A major effort will be required to make the sediment transport instrumentation for the microscale experiments available. The new instrumentation will be incorporated in the microscale experiments and installed at the same locations as the velocity and wave measurements. Simultaneous measurements of the forcing functions and sediment response will allow a direct correlation and ultimate determination of casual relationships.

During the microscale experiments the three-dimensional characteristic of the flow field in the near shore regime will be measured. Longshore currents and their distribution across the surf zone will be determined. The velocity and surface elevation measurements will be used to

NEASHORE SPACE - TIME SCALES

Forcing Function	Space (Meters)	Time (Seconds)
Sea-Swell Waves	20-100 m	3-30
Edge Waves	100 m-	10-
Surf Beat	100 m-	40-200
Rip Currents	30-200 m	10-
Longshore Currents	100 m-	10-
Ocean Currents	500 m-	100-
Tides	300 m-	4.3×10^4
Winds	100 m-	60-
Response Function		
Suspended Sediment		10-
Bed Load		10-
Bathymetry		10^3

characterize the radiation and Reynolds stresses as a function of offshore location. Velocities will be measured over the vertical to determine the mass transport balance in order to determine how the velocity field interacts to cause offshore sediment transport. The existence of rip currents will be looked for during the experiments, and if they are present, they can be measured with the velocity instrumentation. In fact, one of the specific efforts of the experiments will be to determine the influence of rip currents on the sediment transport. The individual measurements are to extend long enough in order to determine the variability in the longshore currents. An important question to be answered is whether or not the surf zone can be treated as essentially a steady state system or does the sediment transport respond primarily to maximum wave conditions followed by quiescent periods in which there is little transport.

The surface elevation will be measured at many locations within the surf zone in order to describe the breaking waves and their transformation, attenuation and eventual run-up on the beach. The waves outside the surf zone will also be measured with the intent of measuring the forcing function outside the surf zone and how it relates to the distribution of currents and waves inside the surf zone with the ultimate objective of tying the two together. The waves are to be measured over a wide band of frequencies including the highest frequencies, the sea-swell band and the long waves including frequencies up to tidal. Determination of the mean values of the surface profile will allow examination of the set-up and set-down within the surf zone and how the areal distribution of mean surface elevation within the surf zone correlates with the dynamics including rip currents.

The wind will be measured within the surf zone in order to determine its importance as a contributing factor to the forcing function and how the wind modifies the wave and breaker field. Concurrent with the measures of the forcing functions will be profile measurements in order to determine the gross response of the bathymetry to the physical environment.

A plan of an envisioned microscale experiment is shown in Figure 2. The approximate locations of current meters, wave gauges and sediment measuring devices are noted. Each current meter measures two orthogonal horizontal components of flow. The total number of channels of recorded data will be on the order of one-two hundred. The appropriate length scales are highly dependent on the beach slope and height and period of incident waves. Since the spatial scales of the physical phenomenon are not yet well understood and the experimental site has yet to be selected, the proposed plan must be viewed as very preliminary. As our understanding of the scale of the forcing mechanisms and sediment response improves, the location and spacing of instrumentation can be optimized.

The macroscale experiments are envisioned as utilizing an effective trap to measure the net longshore transport simultaneously to measure the forcing functions. Initial macroscale experiments will be to evaluate trap effectiveness and to estimate the probable error in measuring the sediment transport with this technique. The trap, or impoundment experiments, will require the measurement of planform in considerable detail. It is planned to use and develop an all-weather system to provide measurements of the profile changes in order to obtain accurate on/off shore measurements during all conditions of the field experiments.

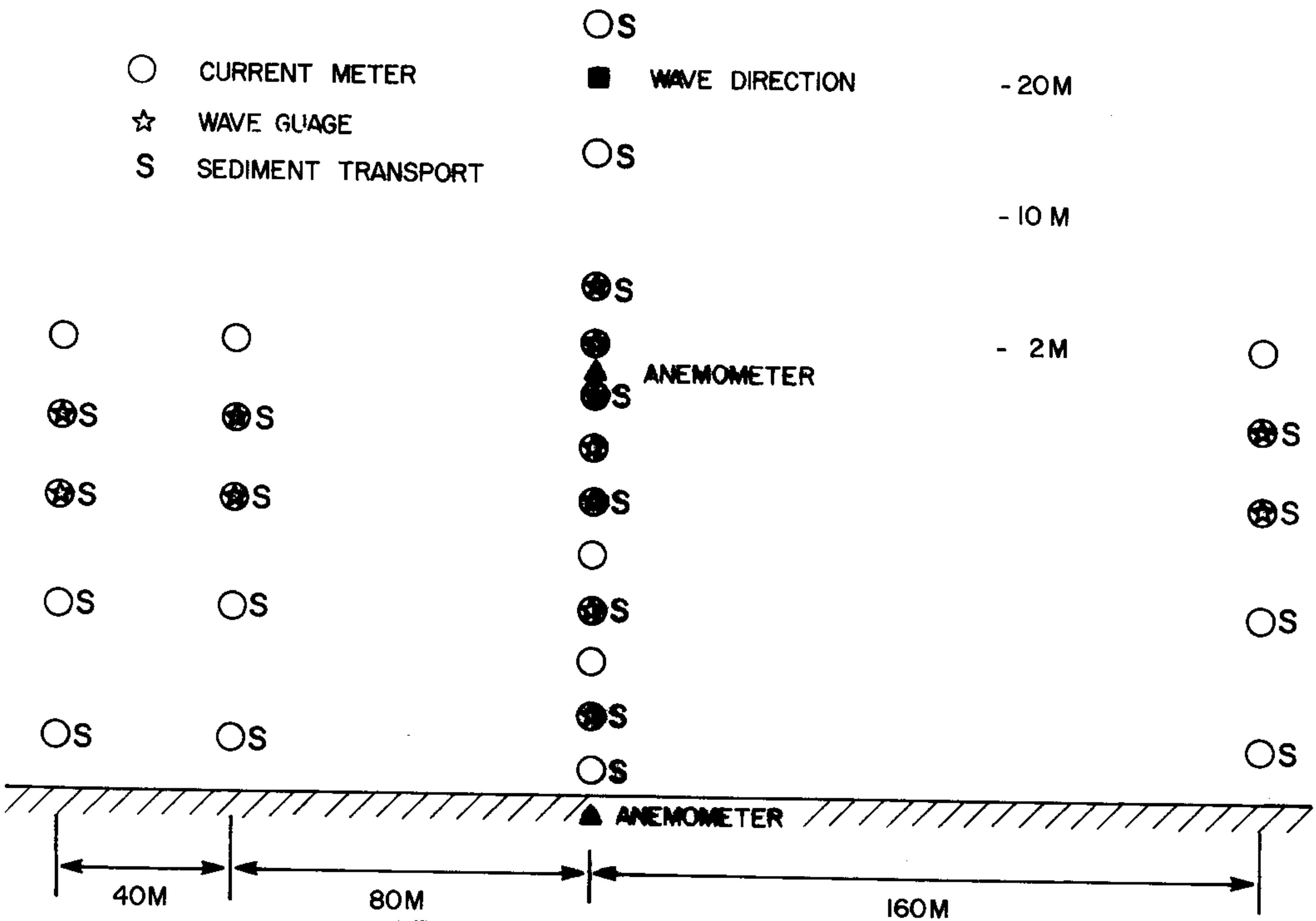


Figure 2. Preliminary microscale experiment plan.

Ultimately, the micro and macro scale experiments are to be performed in conjunction with each other in the major field experiments. The micro scale experiments are to provide the detailed information to assess the macro scale measurements and to allow casual relationship to be developed. The ultimate objective of the program is an engineering predictive formula for sediment transport within the nearshore regime.

AN INVENTORY OF DATA ACQUISITION SYSTEMS FOR COASTAL PROCESS EXPERIMENTS

William L. Wood
Dept. of Geosciences
Purdue University

A primary concern in planning for the National Sediment Transport Study(NSTS) is to establish the suitability and availability of data acquisition systems. Success of the large-scale field experiments, planned for this study, is integrally dependent upon the ease and reliability of recording large amounts of data on a synchronus time base. There are two possible alternatives for establishing an adequate data acquisition system for the NSTS experiments. First, existing data acquisition systems could be combined and/or modified to meet the requirements of the large-scale field experiments. Second, a new data acquisition system could be designed and funded specifically for the NSTS experiments. There are arquments which can be put forward in favor of either of these two alternatives. However, it is obvious that the first alternative can not be adequately evaluated without specific information on existing data acquisition systems. Therefore, the NSTS steering committee requested that an inventory of existing data acquisition systems, suitable for recording field data during coastal processes experiments, be conducted within the research community of the United States. Restriction of this inventory to the United States was predicated on the fact that the Sea Grant sponsored NSTS is designated as a national rather than international program.

It was felt that the simplest and most direct method for conducting an inventory of this scale was to use a survey questionnaire. There were five primary objectives, with which the survey questionnaire was designed to deal. These objectives were: to inventory existing data acquisition systems; to determine the current status of these systems; to assess the compatability of these systems; to determine the suitability of these systems for coastal process experiments; and to determine the availability of these systems for the NSTS large-scale experiments.

The format of the inventory survey was designed to determine the following:

1. Is the system operational or planned?
2. How many channels of data can be simultaneously recorded?
3. What is the sampling rate, range and adaptability of the system?
4. What is the system accuracy, resolution and range?
5. What type of data link and data link transmission are used?
6. What is the systems current location and portability?
7. What type of recording and final data output form are available?
8. What are the power requirements for field systems?
9. Are there provisions for real time reference?
10. What is the suitability or availability of this system for the NSTS experiments?

An initial mailing of twenty-five survey questionnaires was sent to university, government, and private research groups known to be active in coastal process research. A list of those recipients is given in appendix I. Eighty percent of the questionnaires were returned. The specific information from each recipient is given in Table 1.

The results of the survey provided a number of generalizations which will be useful in the planning for the NSTS large-scale experiments. The number of data channels available on any one system is highly variable, ranging from a high of 90 at the Shore Processes Laboratory(SIO) to a low of 4 at R. P. I. Accuracy is more than adequate for the types of input sensors that will be used during the experiments. Resolution of most systems is 12 bits. Sampling rates are highly variable, but almost all systems have an adequate range to accommodate the anticipated data acquisition rate necessary for the NSTS large-scale experiments. The primary data link is hardwire and most systems receive both analog and digital signals. Power requirements for any of the systems can be easily supplied in the field, but most of the systems which have desirable data acquisition specifications, are not easily portable into the field. A wide variety of recording options are available including strip chart, cassette and 7 or 9 track tape, disc, and video display. The final output form of most systems is 9 track tape, which should ease data storage and management problems during the NSTS experiments.

In summary, there appear to be a number of data acquisition systems which could be compatibly incorporated into the NSTS large-scale experiments. The Shore Processes Laboratory(SIO) currently has the greatest number of operational data channels. However, this system would have to be converted to a portable unit for use in the NSTS experiments. Two other systems, at

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Channels	24	32	32	32	23	23	?	32	?	64	4	90	7	2/15	10	N	N	N	N	N	N
Accuracy	I	?	?	.1	.1	.1	?	I	?	I	?	I	.1	I	I						
Resolution	?	12	?	16	16	16	12 16	12	6	.01	8	12	.02	12	12 24						
Data Link	T	Hw	Hw	T	T	T	T	Hw	Hw	Hw	Hw	Hw T	LL	Hw T	IS						
Data Trans.	D	AD	AD	D	D	D	AD	AD	D	A	AD	D	AD	D	?						
Portable	Y	Y	Y	N	N	N	?	Y?	Y	Y	Y?	N	N	Y	N						
Power Req.	D	A	A	D	D	D	A	A	A	A	A	D	A	D	D						
Time Ref.	C	C	A	C	C	C	A	C	?	C	A	C	A	A	C						
Recording	T	TD	Va	T	T	T	?	T	T	ST	VT	ST	TD	ST	T						
Final Output	9	7	9	9	9	9	9	9	7	9	9	9	9	9	C						
Operational	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	YN	Y						
Available for NSTS	?	?	$	?	?	N	?	Y	?	Y	Y?	Y	Y?	Y?	?						

Table 1. Specific responses of survey recipients(respondents listed in appendix I)
Key: Channels, N-none; Accuracy, I-instrument, .1-0.1%; Resolution, 12, 16, 24 bits; Data Link, Hw-hardwire, T-telemetry, LL-lease line; Data Trans., A-analog, D-digital; Portable, N-no, Y-yes; Power Req., A-AC, D-DC; Time Ref., A-available, C-clock; Recording, D-disc, S-strip chart, T-tape; Final Output, 7 or 9 track, C-cassette; Operational, N-no, Y-yes; Available for NSTS, N-no, Y-yes, Y?-doubtful, $-lease.

the Naval Postgraduate School and at the Great Lakes Coastal Research Laboratory(Purdue), have a large number of data channels and are reasonably portable at this time. No single system currently exists which meets all of the anticipated requirements of the NSTS large-scale experiments.

An important factor in planning for the NSTS experiments is the avial-ability of the data acquisition systems. Both site selection criteria and desired wind, wave and current conditions will necessarily limit the number of suitable time periods for conducting the NSTS experiments. Likewise, allowances for sufficient set up time will have to be planned into the overall execution time table. When these factors are considered jointly with the probability of weather conditions appropriate for producing the desired range of forcing conditions, it becomes obvious that a data acquisition system and most of the necessary sensors will have to be committed entirely to the NSTS experiment for long, continuous time periods. Currently, only three groups have indicated that their systems could be committed to this type of semi-continuous usage. Those groups are the Shore Processes Laboratory(SIO), Naval Postgraduate School and Great Lakes Coastal Research Laboratory (Purdue).

A decision on whether to use existing data acquisition systems in a combined and/or modified form, or to acquire a new data acquisition system specifically for the NSTS experiments is not easily evoked from the results of this inventory survey. Clearly, the systems exist which could be combined and or modified to meet the requirements of the NSTS experiments. Availability and portability are the two most limiting factors of existing data acquisition systems, suitable for the NSTS experiments. However, it seems that these two limiting factors are also the most easily resolvable ones. Therefore, it is recommended that initial efforts be directed at modifying existing data acquisition systems to provide the necessary portability. Furthermore, close coordination should be maintained between all of the NSTS investigators so that instrumentation developed or modified for the NSTS experiments is compatible with the primary data acquisition system. This approach should provide the greatest probability of success for the NSTS large-scale experiments.

Acknowledgements

I wish to thank Dr. R. J. Seymour, California Department of Navigation and Ocean Development, and Mr. R. L. Lowe, Shore Processes Laboratory (SIO) for their careful preparation of the survey questionnaire.

Appendix I

Respondents listed in Table 1.

1. Brookhaven National Laboratory
2. Coastal Engineering Research Center
3. Jet Propulsion Laboratory

4-6. NOAA, National Data Buoy Office

7. NOAA, Ocean Engineering Office
8. Naval Postgraduate School
   Dept. of Oceanography
9. Oregon State University
   School of Oceanography
10. Purdue University
    Great Lakes Coastal Research Laboratory
11. Rennsselaer Polytechnic Institute
    Dept. of Electrical Engineering
12. Scripps Institution of Oceanography
    Shore Processes Laboratory
13. Scripps Institution of Oceanography
    Physical Oceanography

14-15. U. S. Geological Survey
16. University of Delaware
    College of Marine Studies
17. University of South Carolina
    Dept. of Geology
18. University of South Florida
    Dept. of Geology
19. University of Virginia
    Dept. of Enivironmental Science
20. University of Washington
    Dept. of Oceanography
21. University of Wisconsin
    Dept. of Civil and Environmental Engineering

Questionnaire recipients, not responding to survey.

1. Boston College
   Dept. of Geology and Geophysics
2. Louisiana State University
   Coastal Studies Institute
3. Massachusetts Institute of Oceanography
   Dept. of Civil Engineering
4. Tetra Tech Inc.
5. Texas A and M
   School of Oceanography
6. University of Calif. , Santa Cruz
   Coastal Marine Laboratory
7. University of Massachusetts
   Coastal Research Center

NSTS REQUIREMENTS FOR INSTRUMENTATION SYSTEMS

Richard J. Seymour
California Department of Navigation
and Ocean Development

In previous papers, Dr. Thornton has indicated the need for simultaneous measurement of on the order of one hundred parameters and Dr. Wood has shown that only a few such systems presently exist.

From the discussion generated at this workshop, it seems clear that the logistical problems at the chosen field site will dictate many of the characteristics of the instrumentation system, such as the means for transmitting data from the sensors to the recording system. Careful consideration was given to the need for this project to purchase a project-owned instrumentation system and the consensus of the group was 1) that this probably would not be required, 2) could only be determined with certainty after the field site selection process, and 3) that a year's lead time was sufficient to activate such a system, if needed.

The state-of-the-art papers made it clear that the capability presently exists to measure and record all of the parameters of interest except the movement of sediment. The measurement of suspended or bedload sediment transport remains the principal developmental problem for this program and requires the highest priority and attention.

WORKING GROUP ON IMPROVING INSTRUMENTATION SYSTEM RELIABILITY

R. P. Savage
Coastal Engineering
Research Center

1. The group began its considerations by "brainstorming" about things that affect instrument system reliability, particularly for the portion of the system located in the surf and nearshore area. The ideas developed are at Attachment 1.

2. The ideas developed were then organized into an outline with the idea that the outline could be used as a checklist to help investigators improve instrument reliability. The outline checklist is at Attachment 2.

2 Attachments

NATIONAL SEDIMENT TRANSPORT STUDY

Workshop on
Improving Instrument System Reliability

Idea List

1. Use floats for currents (use the simplest instrument that will do the job).
2. Use redundancy in measuring methods, instruments and people.
3. Because of unknowns in the environment, overdesign as much as economics and functionality permit.
4. Pretest instruments in the laboratory.
5. Pretest instruments and procedures in the prototype.
6. Combine current measurements with sand flux measurements if practical.
7. Early concentration on sediment measurements is needed.
8. Plan for lightning, ice and other environmental problems, including large waves.
9. Specify instrument reliability needed.
10. Obtain an independent analysis and evaluation of latest state-of-the-art information for instrument systems now in use.
11. Conduct a survey of instrument users asking about kinds of failures.
12. Include error checking techniques in transmission equipment.
13. Check field data for reasonableness quickly (periodically).
14. Plan to eliminate fouling problems, both from floating debris and from plant and animal growth.
15. Consider electrolysis problems in bimetalic designs.
16. Consider mounting problems.
17. Vandalism.
18. Make safety a primary consideration.
19. Consider people problems - tourists, question askers.
20. Watch for marketing managers (they tend to think some equipment solves all problems).

ATTACHMENT 1

Idea List Cont'd

21. Allow instrument people independence in sensor development, but not too much.

22. Make sure moorings are firm.

23. Characterize the extremes; for instance, large waves, spring and neap tides and strong winds.

24. Investigate the possibilities for interference between instruments or different groups of investigators.

25. Consider the possibility of interference from outside sources; for instance electromagnetic radiation, and obstacles to wind flow such as cliffs behind the beach.

26. Be sure that instruments are fully calibrated and that the calibration is periodically checked.

27. Maintainability is an important characteristic in the design and installation of instrument systems.

NATIONAL SEDIMENT TRANSPORT STUDY
INSTRUMENTATION WORKSHOP

Report of Working Group on Improving Instrumentation System Reliability

Outline Checklist

I. REDUNDANCY

- A. Alternate Sensing Methods
- B. Component Duplication
- C. Personnel Cross-Training at <u>All</u> Levels

II. PRE-EXPERIMENT ACTIVITIES

- A. Make Failure Survey
- B. Independent Analysis and Evaluation of Latest Information
- C. Pretesting - Lab and Prototype (Incl. Burn-In)
- D. Reliability Definition and Specification
- E. Extremes Characterization
- F. Overdesign
- G. Checklists
- H. Check for Interference Between Diff. Groups' Instruments
- I. Packaging for Shipment and Ocean Environment

III. ERROR CHECKING

- A. Equipment Error Checking Devices
- B. Prompt, Frequent Data Checking

IV. ENVIRONMENTAL CONSIDERATION

- A. Safety
- B. Extremes Characterizations
  - (1) Equipment survivability
  - (2) Dynamic Range of Variables
- C. People Problems, Vandalism
- D. Fouling (Flotsam + Barnacles)
- E. Electrolysis
- F. Lightning
- G. Ice
- H. Scouring
- I. Burial
- J. EMI/RFI

V. CALIBRATION AND VERIFICATION

ATTACHMENT 2

Outline Checklist Con't

VI. MAINTAINABILITY

A. Ease of Troubleshooting
B. Identify and Provide for Critical Spare Parts
C. Insitu Sensor Change
D. Technical Support Personnel Availability
E. Support Facilities

WORKING GROUP ON STANDARDIZING DATA FORMATS, ANALYSIS TECHNIQUES AND ARCHIVING REQUIREMENTS

R. J. Seymour
Scripps Institution
of Oceanography

The group first evolved a number of potential problem areas that could arise out of a lack of standardization as follows:

a) For specialty analysis techniques, such as calculating a directional spectrum, which are not likely to be repeated from raw data by other cooperating investigators, the other users need to know in advance what type of analysis will be performed so they can plan their own experiment and analysis designs.

b) Timing problems can exist in both the micro and macro scale. Common time reference must be available to sufficient accuracy to allow synchronization of data recorded separately. Also, in cooperative experiments where absolute synchrony is not required, investigators must be assured that they are measuring the same events -- particularly when automatic data cycling is employed.

c) Problems can exist in knowing what data collected by other experimenters is available.

d) The physical transfer of data involves questions of tape read incompatibility, knowledge of calibration format and other use considerations, and the schedule of availability.

e) The question of archiving requirements -- what?, where? and how? -- was also discussed.

f) Concern was expressed over the problems caused by differing interpretations of the same data by separate investigators and how the maximum utilization of data and analyses could be achieved within the program.

g) The question of protection of academic privilege was raised.

It is obvious that these concerns ranged well beyond the topics suggested by the title of the working group session -- although they were all related to the sharing of data and analyses. One of the reasons for this divergence probably stemmed from the early, vigorous determination by the group that no single standard data or analysis format was feasible or desirable for this program because:

a) if a format were sufficiently inclusive to include all possible needs, it would be too cumbersome, and

b) analysis needs vary from experiment to experiment and any meaningful standardization would be too restrictive.

The working group did, however, formulate a number of recommendations based upon the discussion of data handling problems:

a) Individual investigators cooperating in the same experiment should prenegotiate the type of analysis each will perform on his own data and then exchange data and analyses directly, rather than through the Project Leader, as called for in the NSTS Program Plan.

b) Each investigator shall prepare and keep current a data map on all raw and reduced data showing what records are available, the general conditions of the experiment and other information helpful to NSTS investigators in evaluating its usefulness to them.

c) Tapes supplied to the Project Leader for the project archive or for duplication to supply other investigators shall be:

1) nine-track

2) use a universally readable format

3) be condensed to the minimum number by combination and editing

4) shall include a map containing formats, timing convention, calibration factors, etc.

d) The other elements of the Program Plan relating to data exchange -- particularly the 30-day due date and the protection provisions for academic privilege are acceptable as written.

e) Workshops are the best vehicle for data exchange and for integration of findings from different experiments.

f) The archiving function should be turned over to the Environmental Data Service of NOAA at the end of the project.

WORKING GROUP ON REQUIREMENTS FOR ACCURACY AND PRECISION OF MEASUREMENT

R. L. LOWE
Scripps Institution
of Oceanography

It was generally agreed at the outset of our meeting that if a problem existed with the measurement of a parameter it would be a problem of the basic sensor and not of the data acquisition system. Therefore, we discussed the various parameters to be measured and the sensor available for these measurements.

Beach Surveys:

Using present systems (CERC), the horizontal position is known within 1 m and the vertical dimension can be measured to within ± 3 cm (random error). The basic problem is that the vertical measurement is referenced to the sea surface which is changing. Accelerometers could be used but there are stability problems, and for increased precision this technique becomes very expensive. Acoustic methods (within the surf zone) have problems with air bubbles entrained in the water.

For impoundment studies, if the contours are regular only profiles perpendicular to the contours with about 30 meter spacing are needed. But if the contours in the longshore direction are irregular, some longshore profiles will be necessary.

The basic accuracies of the present system are adequate for long-term impoundment studies. But for daily changes, the present system might prove to be too slow, and signal to noise may be a problem.

Velocity:

It would be desirable to determine the relationship between the turbulence level and the suspended sediment. In order to accomplish these, measurements of small spacial and temporal scales are required. With presently available sensors, neither of the scales are small enough to adequately determine the relationship between turbulence and sediment. Ironclad hot film coupled with an electromagnetic current meter (for direction) may satisfy the temporal scale.

It would be desirable to measure the vertical component of velocity near the bottom. This measurement is difficult because the vertical component is an order of magnitude below the horizontal components. This difference leads to an orientation problem and a signal to noise problem.

Some method for measuring the bottom stress would be desirable. Stress plates cannot be used because they would disturb the flow field.

A direct measurement of the turbulent Reynold's stress near the bottom would be of great value, but the problem of accurately measuring vertical velocities makes this a very difficult task.

Bob Dean, University of Delaware, suggested using a GEK technique for measuring the mean longshore current across the surf zone. If the technique could be shown viable, cables of different lengths could be used to obtain the on-offshore structure of longshore currents.

Sea Surface:

For rip current studies, it is desirable to measure the variability (longshore) of setup. To accomplish this measurement, a stilling well technique could be used to avoid some of the problems with surface-piercing staffs. The required accuracy of less than a cm could probably be achieved.

The measurement of the fluctuating part (wave, etc.) is probably adequate using today's sensors. These sensors give correct answers to within a few percent.

Sediment Meters:

This area of instrumentation is by far the most lacking and needs instrument development. At present, order of magnitude type measurement should be strived for. Presently acoustic listening devices are being evaluated for both bedload ans suspended sediment transport.